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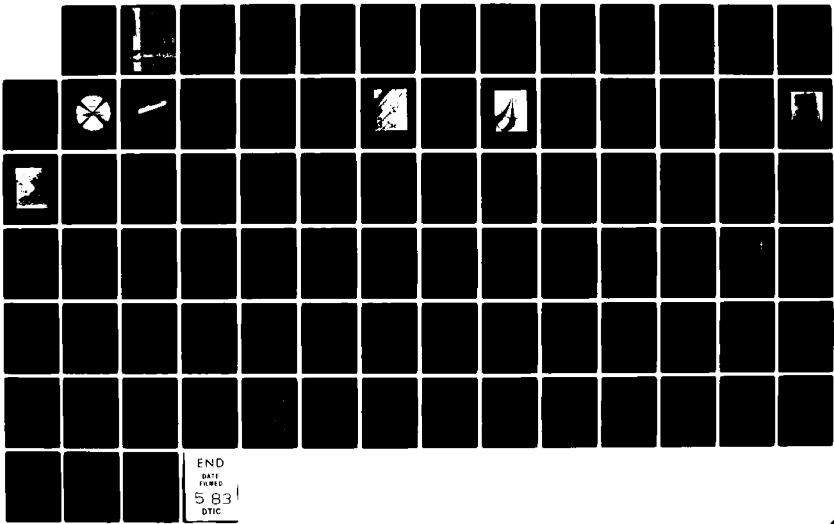

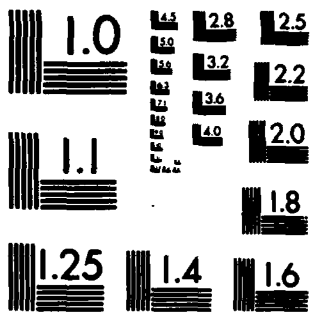
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RAPID RUNWAY REPAIR PROGRAM SUBTASK 1.08 - CONCRETE CUTTING EQUIPMENT EVALUATION

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1 MARCH 1983

FINAL REPORT
JULY 1981 - SEPTEMBER 1982

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESL-TR-82-40	2. GOVT ACCESSION NO. AD-A127 336	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Rapid Runway Repair Program Subtask 1.08 - Concrete Cutting Equipment Evaluation		5. TYPE OF REPORT & PERIOD COVERED Final Report July 81 - September 82
		6. PERFORMING ORG. REPORT NUMBER BDM/W-82-505-TR
7. AUTHOR(s) Moats, R. K., Duchatellier, R. (BDM); Thakur, B.N. (Cushion Cut)		8. CONTRACT OR GRANT NUMBER(s) F08635-80-C-0206
9. PERFORMING ORGANIZATION NAME AND ADDRESS The BDM Corporation 7915 Jones Branch Drive McLean, Virginia 22102		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS JON 21042B64
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Engineering and Services Center Tyndall Air Force Base, Florida 32403		12. REPORT DATE 1 March 1983
		13. NUMBER OF PAGES 75
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited: Approved for Public Release.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Availability of this report is specified on reverse of front cover.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Concrete	Concrete Sawing
Concrete Cutting	Diamond Saw
Cutting Rate	Diamond Saw Blade
Rapid Runway Repair	Bomb Damage Repair

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Diamond saws were identified in earlier studies as a promising technology for cutting concrete for bomb damage repair efforts. Diamond saw blade design parameters (metal bond; diamond type, concentration, and mesh size) were investigated to develop an optimum rapid cutting blade. Blade performance was measured in terms of cutting rate, power requirement and wear performance. Cutting rates

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as high as 4 ft^2/min for a 7-inch deep cut were achieved requiring 34 horsepower. At these high cutting rates, the 24-inch diamond saw blades developed gullet cracks. Data from the test program is interpreted regarding the feasibility of several possible diamond saw systems for obtaining cutting rates of 20 ft^2/min.

sq. ft.

PREFACE

This report was prepared by the BDM Corporation, 7915 Jones Branch Drive, McLean Virginia, 22102, under Contract Number F08635-80-C-0206, for the Air Force Engineering Services Center, Engineering and Services Laboratory, Tyndall Air Force Base, Florida, 32403.

This report summarizes work done between July 1981 and September 1982. Mr. Edgar F. Alexander was AFESC Project Officer.

This report discusses Laboratory Testing of Commercial Products used for Concrete Cutting. The report does not constitute an endorsement or rejection of these products, nor can it be used for advertising a product.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

1. BACKGROUND

This subtask was prompted by the work conducted in preparing the Recommended Research, Development, Test, and Evaluation Plan for Improved Concrete Cutting for Subtask 1.06 of the Rapid Runway Repair (RRR) Program. Diamond saws were identified at that time as being a promising technology for application in bomb damage repair (BDR) efforts. The technology has been highly developed for many commercial applications with equipment being readily available. Diamond saws are capable of accurately aligned cutting and of cutting reinforced concrete. The cutting rate is comparable or exceeds other commercial cutting methods. At the time the RDT&E Plan for Subtask 1.06 was prepared the maximum cutting rate of off-the-shelf diamond saws was estimated at 1 to 3 linear feet per minute in 12-inch thick concrete. Although the current capabilities of diamond saws are suitable to meet commercial needs, they are short of the Air Force requirements to cut 20 to 30 linear feet per minute of 12-inch thick concrete. A research and development program with the objective of developing a diamond saw to meet these Air Force requirements was outlined in the RDT&E Plan prepared for Subtask 1.06.

The inadequacy of off-the-shelf diamond saw equipment to meet the Air Force requirements lies in part with design constraints to minimize cost for commercial applications. The research and development plan recognized this fact and recommended a two-phase program. The first phase was a feasibility assessment of the diamond saw technology to meet Air Force requirements by investigating the performance of several diamond saw blades of varying design characteristics. The second phase of the R&D program will consist of the design, fabrication, and testing of a prototype diamond saw system to meet the Air Force requirements. The decision to implement the second phase is contingent on results of the first phase of the program, which is the subject of this report.

The first phase of this R&D program was initiated in July 1981 when The BDM Corporation subcontracted Cushion Cut to provide data and information necessary to support the feasibility assessment. Cushion Cut's effort included the design and fabrication of a variety of diamond saw blades. The synthetic diamonds Cushion Cut uses in their diamond saw blades are manufactured by the General Electric Company. Tests on these blades were conducted by an independent test laboratory mutually agreed upon by Cushion Cut, BDM, and AFESC.

2. PROGRAM OBJECTIVES

The specific objectives for Subtask 1.08, Concrete Cutting Equipment Evaluation, are to better define the performance characteristics of cutting

concrete with diamond saw blades, and to investigate the possibility of significantly increasing the speed of cutting operations. This effort serves as Phase 1 of the R&D plan developed in Subtask 1.06 as discussed above.

The performance goals are that a rapid concrete cutting system be able to cut 12-inch thick nonreinforced Portland cement concrete at a rate of 20-30 linear feet per minute with a saw blade lifetime exceeding 1000 linear feet. This level of performance will allow the damaged concrete to be cut from around the edges of four 60-foot diameter craters in less than 1 hour without a need for replacing blades. A major goal of this program is to evaluate the feasibility of such a system through an estimate of the design. This includes examining the following: crucial design parameters, design scaling data, and alternative design trade-offs.

Consistent with these objectives are the following program requirements: to design and fabricate diamond saw blades of various characteristics, and to test the blades to obtain data on pertinent design parameters necessary for designing a rapid concrete cutting system. The technical approach for accomplishing these objectives is described in Section II.

SECTION II

TECHNICAL APPROACH

1. BLADE DESIGN AND PRODUCTION

As indicated in Section I, cost is a major consideration in commercial diamond saw equipment design. For a diamond saw blade there is a trade-off between its potential cutting speed and blade wear. Because of these economic considerations diamond saw blades capable of producing high cutting rates have not been seriously investigated. This subtask includes a research effort to design blades for rapid concrete cutting. The ultimate goal is a diamond saw blade capable of achieving a cutting rate that exceeds 20 linear feet per minute in 12-inch concrete with a blade-wear lifetime of greater than 1,000 linear feet.

A typical diamond saw blade is shown in Figure 1. The major features of the blade are identified in the figure. The segments located on the perimeter of the blade contain the diamonds which do the actual cutting. The alloy steel core serves to transmit power from the arbor to the segments. The dimensions of the arbor hole and pin hole depend on the type of saw on which the blade is mounted; some saws do not require the pin hole. Gullets are located along the edge of the blade into the steel core and serve to remove swarf (abraded concrete-water mixture) from the kerf. Between the gullets, segments are welded or brazed to the outer edge of the core. Each segment contains diamonds impregnated in a metal bonding matrix. A segment is shown in Figure 2.

A diamond saw blade cuts concrete by the action of the diamonds against the concrete. As a blade cuts, diamonds may be worn, crushed, or pulled out of the metal matrix. To continue to cut effectively, the metal matrix must also wear at a rate which exposes "fresh" diamonds to the surface. To reduce wear on the steel core and minimize power requirements from the friction of the core against the sides of the kerf, the segment thickness is greater than the core. The cutting rate and segment wear rates also depend on other factors, which include: characteristics of the material being cut, particularly aggregate hardness in concrete; the depth of cut; arbor speed and horsepower, with; blade dimensions. In designing diamond saw blades for a particular application the effects of these various factors and trade-offs among them must be carefully considered.

To investigate the effects of various blade design parameters to enhance cutting speeds in concrete, 12 blades were fabricated. The following design parameters differed for the various test blades:

a. Metal bonding matrix,
b. Diamond type,
c. Diamond mesh size,
d. Diamond concentration, and
e. Blade dimensions

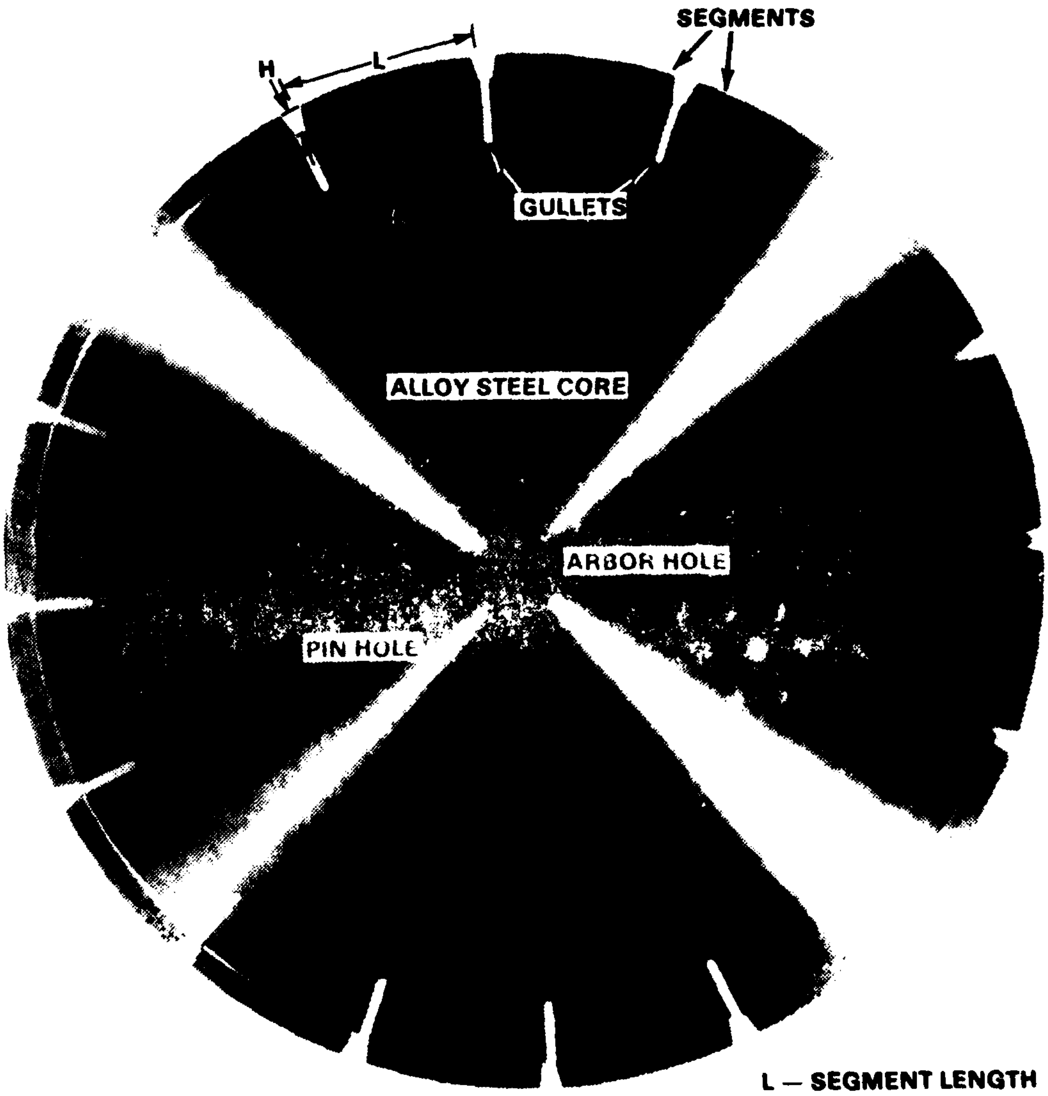


Figure 1. Features of a Typical Diamond Saw Blade.

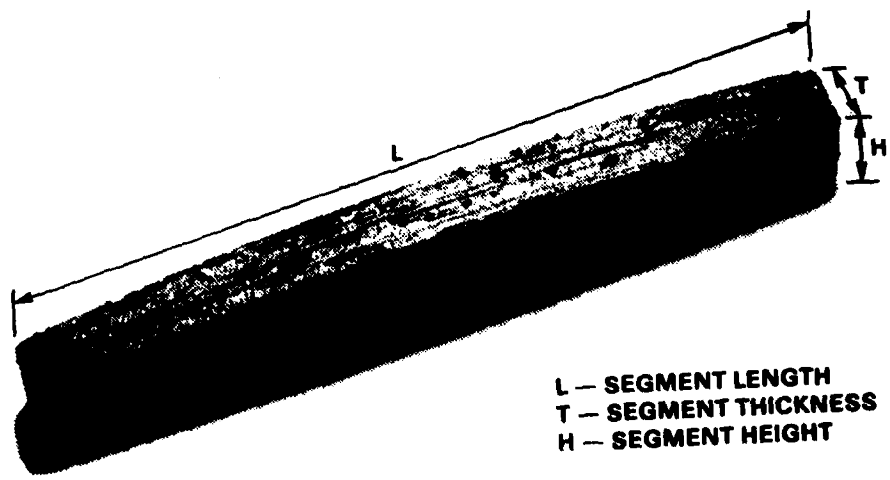


Figure 2. A Diamond Saw Segment.

The specific range for these parameters was determined in part by an iterative testing program described in detail later in this report. However, the basic data characterizing the test blades are given in Table 1.

(1) Metal Bonding Matrix. The physical characteristics of the bonding of the diamonds in the segment play a critical role in the performance of a diamond saw blade. The diamond holding medium of the segment is generally a metallurgically prepared matrix, commonly known as the metal bond. High temperature processing is used to consolidate metal powders to form the metal bond. Care must be taken in this process to preserve the integrity of the diamonds because of their potential reactivity with components in the metallurgical matrix. Some of these components can facilitate partial conversion of the diamonds to graphite. Other properties of the metal matrix which require compatibility with diamonds are thermal expansion, thermal conductivity and the wetting characteristics of the bond material to the diamond surfaces. An additional factor which affects bonding of the diamonds is the porosity (amount of small pores) of the matrix. A lower matrix porosity results in better bonding.

The material to be cut generally dictates the type of diamond blade matrix to be used. The cutting process erodes both the metal matrix and diamond particles. For an efficient cutting operation, the matrix and diamond erosion rates must be compatible. If the material being cut is very abrasive and the matrix is not very wear-resistant, erosion of the matrix will take place at an extremely fast rate and the diamond particles will fall out without being used. This is an inefficient use of expensive diamond particles. On the other hand, if the material being cut is non-abrasive and the matrix is extremely wear-resistant the erosion rate of the matrix is too slow to surface new diamond edges to do the cutting. As a result, the diamond particles will then begin to polish and the cutting process will slow considerably. Depending on the application, the most efficient use of diamond particles occurs when the matrix composition is such that its erosion occurs at a compatible rate with the diamond erosion. For this program, the following four different matrix material compositions were tested: bronze, steel, cobalt, and cobalt-iron.

Hardness of the bond matrix gives an indication of its erosive wear. A quantitative measure of the hardness of a material is given by its Rockwell B value. The Rockwell B hardness is determined by applying a spherical steel indentor to the material. Higher Rockwell B values indicate harder materials. The hardness of a metal bond will depend not only on the metal itself, but also on the porosity. For this reason hardness is used as a control parameter in the production of the segments.

As described above, to have an effective diamond saw blade, diamond cutting surfaces must be exposed at the proper rate to the surface of the segment. A microscopic inspection of the surface can provide a great deal

TABLE 1. TEST BLADE CHARACTERISTICS.

Blade	Blade Diameter (mm)	Core Thickness (mm)	Segment Height (mm)	Segment Thickness (mm)	Segment Length (mm)	Segments Per Blade	Bonding Matrix Base	Bond Hardness Rockwell B	Synthetic Diamond Type	Diamond Mesh Size	Diamond Concentration (%)
XC 1839	616	4.97	6.35	7.77	55.2	33	Bronze	55	Strong crystals	30/40	50
XC 1840	616	4.97	6.35	7.77	54.0	33	Steel	94	Strong crystals	30/40	50
XC 1841	616	4.97	6.35	7.77	54.0	33	Cobalt	102	Strong crystals	30/40	50
XC 1842	618	4.97	7.14	7.77	54.0	33	Cobalt-Iron	122	Strong crystals	30/40	50
XC 1881	614	4.97	5.16	6.22	54.0	33	Bronze	57	Strong crystals	30/40	25
XC 1882	614	4.97	5.16	6.22	54.0	33	Bronze	58	Med. strong crystals	30/40	25
XC 1883	614	4.97	5.16	6.22	54.0	33	Bronze	56	Strong and friable crystals	30/40	25
XC 1935	619	4.97	8.73	6.22	54.0	33	Bronze	60	Strong crystals	25/35	25
XC 1936	619	4.97	8.73	6.22	54.0	33	Bronze	61	Strong crystals	35/40	25
XC 1937	619	4.97	8.73	6.22	54.0	33	Bronze	62	Strong crystals	40/50	25
XC 1970	619	4.90	8.70	6.20	54.8	33	Bronze	56	Strong crystals	30/40	20
XC 1971	619	4.90	8.70	6.20	54.8	33	Bronze	57	Strong crystals	30/40	15

of information about the bonding of the diamond and the blade's performance. Figure 3 shows a magnified portion of a segment employing a bronze metal bonding matrix. The extent a diamond protrudes above the bond surface and the way in which the metal matrix trails off a diamond on a used blade are indicators of the match between the metal bond and the material being cut, and of the operating conditions. Additional information can be obtained from observing the percentage of diamond sites which have whole diamonds, crushed diamonds, or are vacant, the diamond having popped out. This information can indicate if the metal bond is holding the diamond sufficently tight or if better performance (in terms of the use of the diamonds) could be obtained by altering sawing parameters such as arbor rotational speed.

(2) Diamond Type. A variety of "types" of diamonds is available to be used in diamond saw blades. Although all diamonds are the same allotropic form of carbon, they can differ in numerous ways. They can have different shapes; cubic crystals, octahedral crystals, and crushed particles of irregular shapes are examples. Different impurities can be present in the stones, resulting in different physical characteristics. These differences result from the different conditions under which the diamond was formed. In manufacturing synthetic diamonds the conditions can be controlled to yield a variety of different types of diamonds. Because of controlled properties of the synthetic diamond particles, such as the cutting points, friability and temperature dependence, synthetic diamonds are more commonly used in industrial applications than naturally occuring diamonds. Reliable availability is another reason for wide-spread acceptance of synthetic diamond grit. In the construction market it has been observed that synthetic diamonds provide faster cutting rates. The advanced state of synthetic diamond manufacturing technology allows a level of control that permits tailored cutting properties. Three synthetic diamond types were tested to determine the best for high speed concrete cutting. They are characterized as strong crystals, medium strong crystals, and strong friable crystals.

(3) Diamond Mesh Size. Diamond saw blades were also produced with diamonds of varying mesh size. The particle size distribution plays a very significant role in determining the cutting speed and life of a diamond blade. For a known diamond concentration, optimum cutting speed and life are obtainable if the selection of mesh size is appropriate. The matrix composition and the nature of application, however, have a pronounced influence on these optimum parameters. If the particle size is too coarse, the cutting speed is generally slower because the erosion of large diamond particles takes place at a slower rate, and, as a result new cutting points do not surface fast enough. By the same token, if the particle size is too fine, there are too many particles in a fixed amount of diamonds, and a polishing effect results. In cutting concrete, the optimum cutting speed and life are generally obtainable in the US mesh range of 20 to 50 for commonly used bond systems. Three diamond sizes were tested to determine the optimum size for fast cutting.

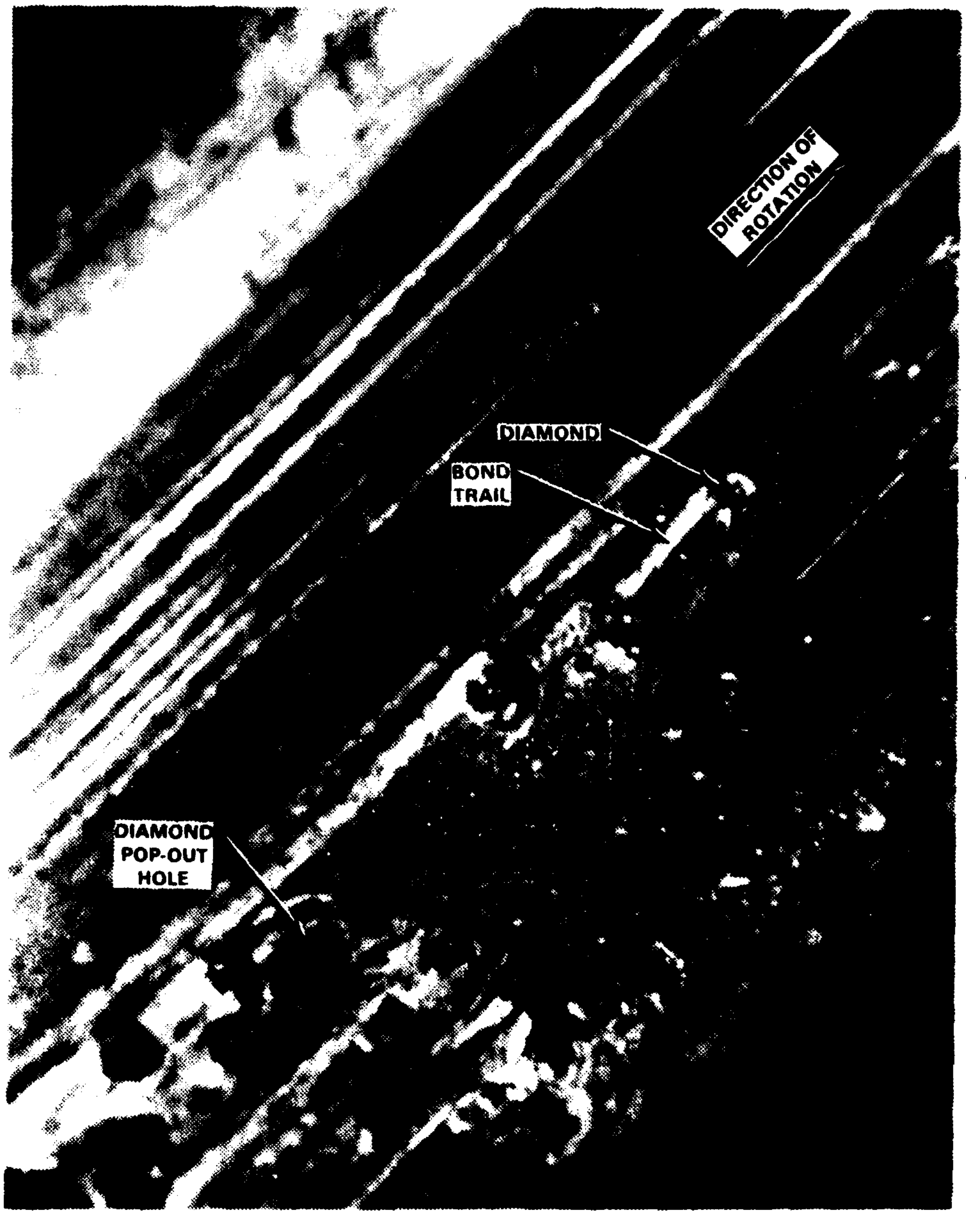


Figure 3. Magnified Portion of a Segment on an Used Blade.

(4) Diamond Concentration. A closely related design parameter is the diamond concentration. Diamond concentration is measured as a percentage of a standard weight of diamonds per volume (72 carats/cubic inch) of segment; thus a 25-percent concentration is 18 carats per cubic inch. In general, a longer cutting life is obtained with a higher concentration of diamonds. The speed of cutting is reduced, however, with an excessive amount of diamonds in the matrix. It is worthwhile to note that the role of the matrix is to retain diamond particles in a rigid body. If there is inadequate bonding matrix, the diamond-containing segment will be extremely brittle and fragmentation of segments will result. Diamond particles will be prematurely lost and the product life will go down substantially. A softer matrix can digest a higher concentration of diamonds. Two concentration levels were tested to determine an optimum diamond concentration.

(5) Other Design Parameters. In addition to the bonding and diamond characteristics the dimensions of a segment also impact cutting performance. Qualitatively as the segment height (Figure 1 and 2) is decreased there is a reduction in friction against the sides of the kerf. This results in a more free-running blade but this change also decreases the blade's lifetime. An additional consideration in regard to blade lifetime is the proper choice of segment height relative to thickness (Figure 2). Ideally the segment should be designed to wear down, so that the segment thickness approaches that of the core only after essentially all the segment height is gone. Blades tested in this program were fabricated with differing segment dimensions.

A design process that must also be considered in fabricating an efficiently operating diamond saw blade is blade tensioning. Nonuniformities and stresses in the blade can result in wobbling or vibrations when it is subjected to centrifugal forces at high rotational speeds. Vibrations can also result if a blade encounters isolated areas in the material being cut which have a radically different hardness (e.g., reinforcing steel in concrete). To remedy these problems diamond saw blades are "put into tension" by changing the modulus of elasticity in certain key areas of the blade through work hardening the metal. Generally this is accomplished by judiciously hammering the appropriate areas of the blade core (Figure 4). When properly tensioned a blade will operate more smoothly within a range of rotational speeds which include the arbor speed of the saw. Operating the blade at rotational speeds higher or lower than this range will result in vibrations. Proper tensioning of diamond blades becomes more important the larger the blade.

For rapid concrete cutting, the diamond saw blade is under substantial mechanical loading, in addition to the heating that results from friction. These effects can cause stress, fatigue and material failure in the blade. The gullet slots, arbor hole area, and segment bond matrix are particularly susceptible parts of the blade. Application of a coolant fluid, generally water, is necessary to reduce these effects. The problem can also be decreased by changes in the alloy composition of the core, or, to a lesser degree, by some of the design parameters discussed above. All of the

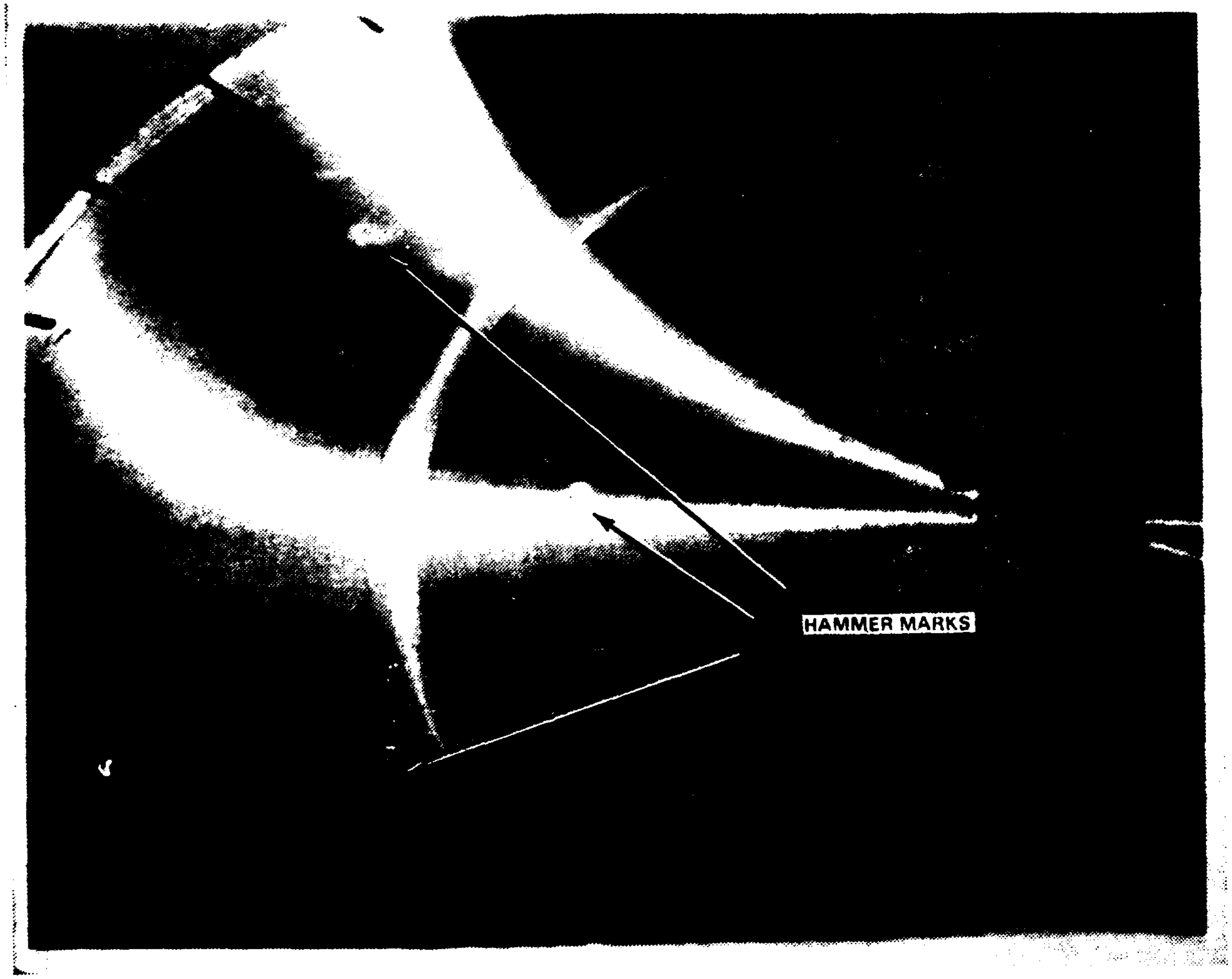


Figure 4. Hammer Marks from Blade Tensioning Process.

diamond saw blades fabricated for this program had the same type of steel core.

2. TEST APPROACH

The approach taken in the fabrication and testing of diamond saw blades for this program was one of successive refinements to identify optimum design parameters. The test program consisted of four phases. During each phase, blades varying in a particular design parameter were tested and the results were used to recommend the design of blades to be tested in the next phase. The major parameters investigated in each of the four phases are listed below.

a. Phase I - Metal bonding matrix
b. Phase II - Diamond type
c. Phase III - Diamond mesh size
d. Phase IV - Diamond concentration

Testing also developed data on cutting performance as a function of sawing parameters such as depth of cut. Table 2 summarizes the tests conducted during each phase. Test reports describing details of each of the tests are contained in the Appendices. A brief summary of the objectives of each phase of the testing is given below.

In Phase I, four different blades were tested, each with a different metal matrix bonding system. The objective of this phase was to establish the best of these bonding systems to be used in fabricating blades for high speed cutting. The four bonding materials investigated were bronze, steel, cobalt and cobalt-iron. In addition to this information, Phase I also served to provide other data. Data on cutting performance (power requirement and blade wear) were developed both as a function of the depth of cut for a fixed cutting rate and as a function of traverse speed at a constant cutting depth.

The objective of Phase II was to investigate the performance of three different types of diamonds for rapid concrete-cutting applications. The three different diamond types can be characterized as strong crystals, medium strong crystals, and strong friable crystals.

Phase III testing investigated the performance of three diamond saw blades each containing diamonds of a different mesh range. These mesh ranges were 25/35, 35/40, and 40/50. The information from this phase of testing can be used to help establish an optimum mesh size for rapid concrete-cutting applications.

The objective of Phase IV was to determine the effects of various diamond concentrations on rapid concrete cutting blades. This phase focused on the following two concentration levels: 15 and 20 percent.

TABLE 2. TEST CONDITIONS.

	Depth of Cut (mm)	Traverse Rate (cm/min)	Cutting Rate (cm^2/min)	Arbor Speed (RPM)	Coolant Flow (ℓ/min)	Blades Tested	Design Parameter Tested
Phase I							Bond Matrix
Test 1	63.5	91.4	580	1450	13	XC1839, XC1840 XC1841, XC1842	
Test 2	88.9	65.3	580	1450	13	XC1839, XC1840 XC1841, XC1842	
Test 3	177.8	32.8	580	1450	13	XC1839, XC1840 XC1841, XC1842	
Test 4	177.9	65.3	1160	1450	13	XC1839	
Test 5	177.8	98.0	1740	1450	13	XC1839	
Test 6	177.8	130.6	2320	1450	13	XC1839	
Phase II							Diamond Type
Test 1	177.8	130.6	2320	1450	38	XC1881, XC1882 XC1883	
Test 2	177.8	195.8	3481	1450	38	XC1771, XC1882 XC1883	
Phase III							Diamond Mesh Size
Test 1	177.8	163.3	2903	1450	38	XC1935, XC1936 XC1937	
Phase IV							Diamond Concentration
Test 1	177.8	163.3	2903	1450	38	XC1970, XC1971	
Test 2	177.8	212.1	3771	1450	38	XC1970, XC1971	

During each phase of the test program, information developed in previous phases was employed to fabricate more productive diamond saw blades. The test program also developed information relevant for scaling the equipment.

SECTION III

TEST RESULTS

1. GENERAL RESULTS

This section summarizes the data contained in the test reports (Appendices A-D). The data are analyzed to provide pertinent information for estimating the design of diamond saw systems to meet Air Force concrete cutting requirements. The results also provide a better picture of the current concrete cutting capabilities of diamond saws.

a. Test Blade Cutting Rates

During the course of this program diamond saw blades with different characteristics were fabricated and tested with some yielding cutting rates up to 3771 cm^2/min (4 ft^2/min). This performance is an improvement over the 929 to 2788 cm^2/min (1-3 ft^2/min) rate which was estimated at the time the RDT&E Plan for Subtask 1.06 was submitted. The enhanced cutting capability of these special blades is also evident from the fact that the blades cut at rates up to 6.5 times the test rate used as an industrial standard.

Cutting tests with these blades were conducted in a concrete which is considered of medium difficulty to saw. It is estimated that the cutting rates would double in a concrete considered soft to saw, such as when limestone aggregate is used. However, concrete containing hard aggregate, like certain types of flint, would result in slower cutting rates.

b. Test Blade Wear

Data obtained from the cutting tests can be used to estimate the lifetime of those blades which are capable of cutting at 4 ft^2/min. The lifetime of the segments, in terms of area of concrete sawn, lies between 540 and 940 ft^2 of concrete depending on the design parameters of the blade. The method for estimating this lifetime will be discussed in detail later in this section. In addition to segment wear, at high cutting rates and particularly for deep cutting, cracking of the steel cores becomes a problem. The problem is more pronounced for deep cutting (7 inches or deeper) because a greater length of the blade perimeter is acting as a cutting surface against the concrete. As described in Section II, the gullets are particularly vulnerable to this problem because the stress in those areas can result in fatigue and material failure. Figures 5 and 6 show magnified views of typical gullet cracks which appeared as a result of blade testing. Measures to help remedy this problem will be discussed later in the report.

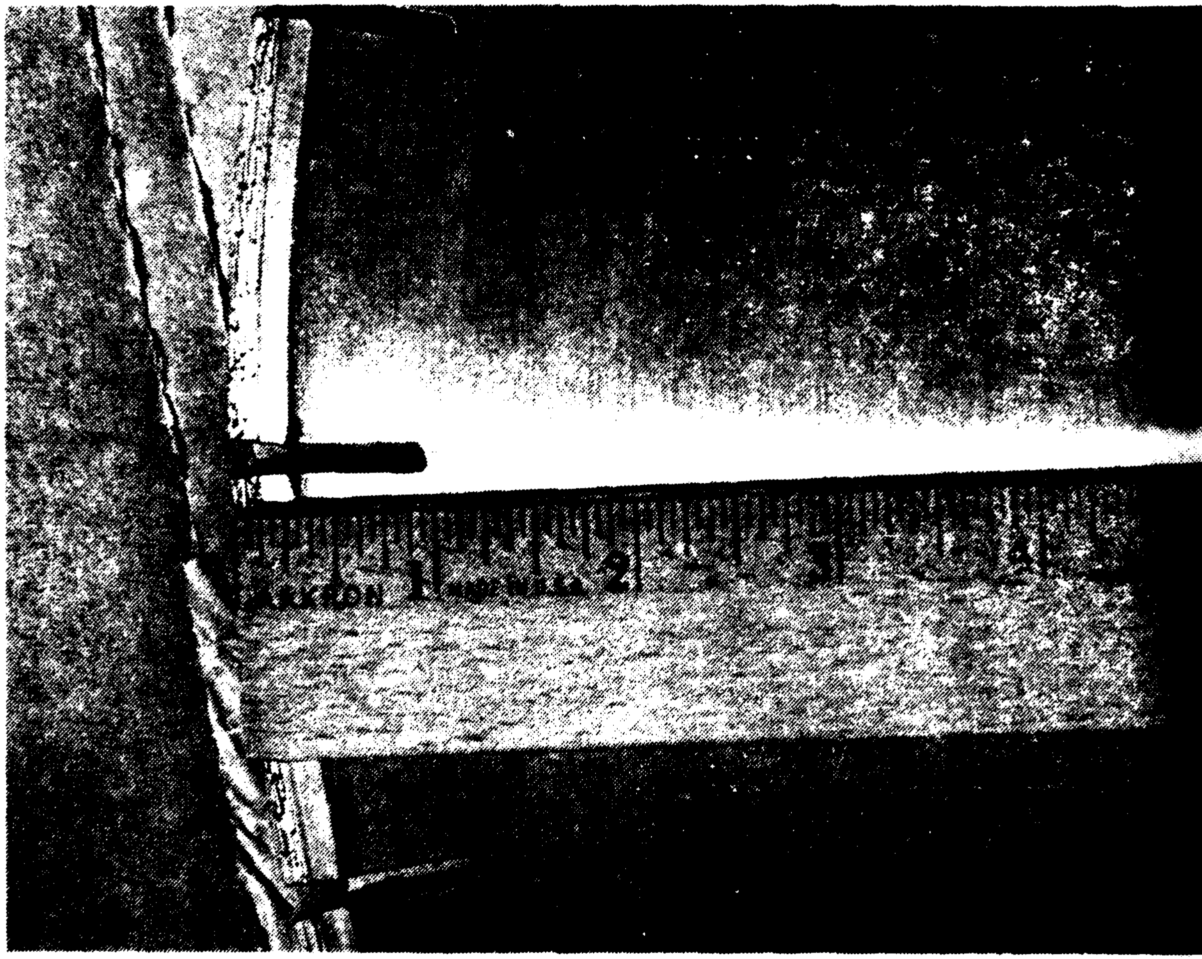


Figure 5. Closeup of Gullet Area on a Used Blade.

Figure 6. Closeup of a Gullet Crack.

2. MEASURING THE CUTTING PERFORMANCE

The testing program uses several factors to serve to measure cutting performances for the different test blades. These include the following: cutting production rate; average power requirement; wear performance, and physical characteristics of the used blades.

a. Cutting Production Rate

The cutting production rate is a measure of the quantity of material being sawn in a given period of time. It is calculated by multiplying the depth of cut by the traverse speed. Cutting a 1-foot deep kerf at a traverse speed of 30 ft/min yields the production rate goal, discussed in Section I, of 30 ft^2/min. Values for the cutting production rates contained in the test reports (Appendices A-D) are generally given in cm^2/min. These can be converted to ft^2/min by multiplying by 1.08×10^{-3} ft^2/cm^2. (Other useful conversion factors are given in Appendix E.)

The cutting production rate is obviously an important measure of performance of the blade when the goal is to develop a rapid concrete cutting system. In the tests the maximum possible cutting rates were limited by two basic factors. The first, and more important, was that the blade cores developed gullet cracks. Generally, when this occurred, further tests at higher production rates were not conducted. The second limiting factor was the maximum power output the Patch-Wegner saw could deliver to the blade. This is approximately 40 horsepower. However, this power level was sufficient to cause many of the blade cores to crack.

b. Average Power Requirement

The average power requirement to maintain a constant arbor speed was determined in the tests with an integrating watt meter. This value provides a good measure of the cutting efficiency of the blade. A blade with a lower power requirement cutting at the same production rate as other blades can potentially operate at higher production rates than the others without stalling the engine or being subjected to material failure. Thus the average power requirement is an especially important quantity to monitor when varying design parameters with the goal of a rapid cutting blade.

c. Wear Performance

Wear performance is defined by the amount of material sawn divided by the average radial wear of a blade. In the test reports (Appendices A-D) the wear performance is given in units of m^2/mm. The larger this quantity, the more wear resistant a blade is and the longer the expected lifetime of the blade. An estimate of the average lifetime of a blade, in terms of linear feet of sawing, can be calculated by multiplying its wear performance value by the segment height, then dividing by the depth of the cut. For example:

$$\text{lifetime} \approx (\text{wear perf.}) \times (\text{segment height}) \times (\text{conversion})/\text{depth of cut}$$
$$\approx ((6\ m^2/mm)(8\ mm)(10.76\ ft^2/m^2))/(1\ ft) = 517\ ft$$

The accuracy of this estimate depends on how close the actual sawing conditions (depth of cut, traverse speed, arbor speed, etc) and concrete characteristics are to those used to measure the wear performance.

d. Physical Characteristics of the Used Blades

The test program included a microscopic examination of the diamond saw blades after they were tested. The examination provided information regarding the percentage of diamonds left whole, crushed, and popped out, along with the wear of the metal bond. This information, as discussed in Section II, is helpful in interpreting blade performance.

3. OPTIMIZATION OF DESIGN PARAMETERS IN THE TEST PROGRAM

To optimize cutting speed, information on a design parameter investigated in one test phase was used to choose a best value for the design of blades for subsequent tests.

Although this process provides a rapid focusing on a good blade design for rapid cutting, it does not provide the comprehensive data which clearly identify the relative importance of each design parameter. Some indication of relative importance is given, however, particularly among parameters significantly affecting performance. The effects of each of the four design parameters investigated on cutting performance are discussed below in what is estimated to be their relative order of importance.

a. Bond Matrix

Of the design parameters investigated the bond matrix appeared to have the most dramatic effect on cutting performance. In the first phase of the test program, blades with different metal bond systems were tested. The bronze bond matrix used in blade XC 1839 operated at substantially lower power requirements at a cutting speed of 580 cm^2/min (0.62 ft^2/min); the other blades required from 37 to 74 percent higher power levels. At higher cutting speeds the blades with metal bonds other than bronze would either stall the spindle motor or begin to flex during the cut.

More information is contained in Appendix A on the tests conducted on the various metal bonds. The cutting performance of the blade depends on complex metallurgical and physical characteristics of both the metal bond material itself and its interaction with the diamonds, as discussed in Section II. The results listed in Table 3 indicate there is little correlation between the Rockwell B hardness value and either the average power requirement or the wear performance. This suggests other physical characteristics are also important.

TABLE 3.. METAL BOND MATRIX PERFORMANCE AT 63.5 mm DEPTH OF CUT AND 580 cm^2/min CUTTING RATE

Blade Number	Metal Bond	Hardness Rockwell B	Average Power (kW)	Wear Performance (m^2/mm)
XC1839	Bronze	55	13.1	44.7
XC1840	Steel	94	20.7	71.1
XC1841	Cobalt	102	18.0	78.2
XC1842	Cobalt-Iron	122	22.9	52.6

TABLE 4. EFFECT OF DIAMOND CONCENTRATION ON CUTTING PERFORMANCE.

Blade Number	Cutting Rate (ft^2/mm)	Diamond Mesh Size	Diamond Concentration (%*)	Average Power (kW)
XC1839	2.50	30/40	50	32.4
XC1881	2.50	30/40	25	18.0
XC1936	3.13	35/40	25	25.2
XC1970	3.13	30/40	20	12.4
XC1971	3.13	30/40	15	7.9
XC1970	4.06	30/40	20	29.4
XC1971	4.06	30/40	15	25.4

*A 100-percent diamond concentration is defined as 72 carats/in^2

b. Diamond Concentration

The next largest effect on performance appeared to be the diamond concentration. As the diamond concentration decreased, the cutting rate increased. During most of the tests the diamond mesh size was constant as the diamond concentration was varied. Table 4 summarizes the test data and shows that for a fixed cutting rate the average power requirement decreases with decreasing diamond concentration. Because the mesh size is essentially constant for these tests, decreasing the concentration reduces the number of diamonds on the cutting surface, resulting in a more free-cutting blade.

c. Diamond Mesh Size

The effect of varying the mesh size for a fixed diamond concentration was investigated in the third phase of the testing program (Appendix C). It should be noted that the mesh sizes recorded in Appendix C are estimates based on the microscopic examination of the used blades. The actual mesh sizes were 25/35, 35/40, and 40/50 as shown in Table 1. The tests indicated no significant difference in the average power requirements for the two blades with coarser mesh size diamonds; but the blade with the 40/50 mesh diamonds required approximately 20 percent more power to maintain the same cutting rate (see Table A-6). As discussed in Section II there exists an optimum diamond mesh range for a fixed diamond concentration and cutting conditions. For the cutting conditions used in Phase III (7-inch deep cut at approximately 5.4 ft/min), the optimum range appears relatively broad (25-40 mesh or possibly coarser) with performance rapidly deteriorating at finer mesh sizes.

d. Diamond Type

The results of the tests on the three blades, each containing a different type of diamond, are summarized in Table 5. Additional data are presented in Appendix B. The table shows that there is not a large difference in performance for the three diamond types investigated in terms of the average power requirement. The strong crystal diamond used slightly less power at each of the two different cutting rates. As the cutting rate increased the spread of power requirements for the three different diamonds also increased, implying that at higher cutting rates the differences could be substantial.

Table 5 contains information reflecting differences in strength and friability of the diamonds. Microscopic examination after the tests revealed that both the medium strong crystals and strong friable crystals resulted in a larger number of crushed stones and less popouts than the strong crystals. As expected, the test using medium strong crystals resulted in the largest percentage of crushed stones.

TABLE 5. EFFECT OF DIAMOND TYPE ON CUTTING PERFORMANCE.

Blade Number	Cutting Rate (ft^2/mm)	Diamond Type	Crystal Condition %			Average Power (kW)	Wear Performance (m^2/mm)
			*W	C	P		
XC1881	2.50	Strong Crystals	55	7	38	18.0	19.3
XC1882	2.50	Med. Strong Crystals	40	30	30	19.4	15.4
XC1883	2.50	Strong Friable Crystals	41	25	34	19.0	16.0
XC1881	3.75	Strong Crystals	48	18	34	26.4	14.7
XC1882	3.75	Med. Strong Crystals	37	32	31	29.7	10.4
XC1883	3.75	Strong Friable Crystals	48	25	27	28.1	10.3

*Whole Crushed Popout

4. PERFORMANCE AS A FUNCTION OF SAWING PARAMETERS

This subsection examines trends and other relevant data for the purpose of estimating the design requirements and feasibility of diamond saw concrete cutting systems for cutting 20 linear feet per minute in 1-foot thick concrete.

As described earlier, the test program was geared toward rapidly optimizing the diamond saw blade design. This approach was at some expense of thoroughness, but certain trends and major system design considerations still became evident.

a. Power Requirements

Power requirement plays a major role in determining the size, weight, maneuverability, and cost of a concrete cutting system. For this reason specific data were gathered on power requirements not only for different blade types, but also while varying the cutting operation. Care was used in examining these data so that a change in power requirement could be attributable to only the variable of interest, and so as to minimize the influence of other factors such as statistical variations between blades, concrete samples, etc.

(1) Power Requirements vs. Traverse Speed at a Fixed Cutting Depth. In Figure 7 the average power requirement is plotted against traverse speed for a 7-inch deep cut. The data from blade XC 1839 gave results appearing to be linear except for the test conducted at the highest power level. The data points for blades XC 1881, XC 1936, and XC 1970 also are approximately linear, although the data point for blade XC 1936 is slightly off the line. Blade XC 1936 had a finer mesh range of diamonds than the other blades which may have caused its behavior to differ. If one assumes an analogous linear behavior for data from blade XC 1971 a straight line can be drawn through the two points. By extrapolation and assuming linearity the data can be used to scale the power requirements to faster cutting rates, as shown in Figure 8.

The three lines in Figure 8 correspond to diamond concentrations of 50, 20, 25, and 15 percent and can provide the related range of power required for a particular cutting rate. The accuracy of a power requirement estimate using this figure depends on several factors. It is based on data for a 7-inch depth of cut, thus, its use is most accurate for 7-inch deep cutting. Data on the effect of changing the depth of cut are discussed later. A second factor affecting accuracy is how far from the existing data is the power requirement being extrapolated. An extrapolation far beyond existing data can result in significant errors if the actual scaling is not linear, but just appears so in the limited range where data are available. This is a definite danger for trying to estimate 20 ft^2/min data from the data known only to 4 ft^2/min rates, because effects such as material failures, heat losses and other power losses could increase nonlinearly.

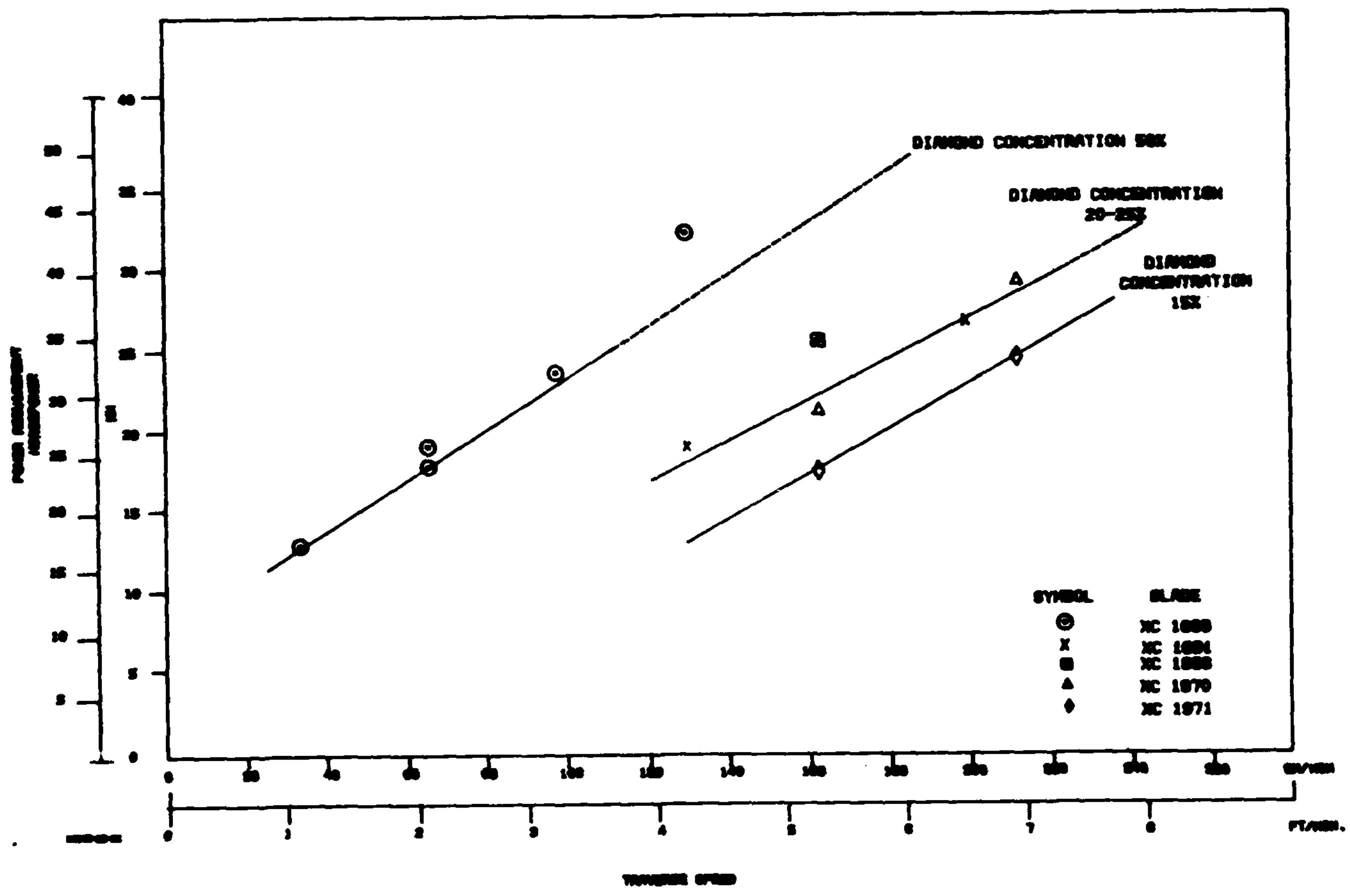


Figure 7. Power Requirement vs Traverse Speed for a 177.8 mm (7-inch) Deep Cut.

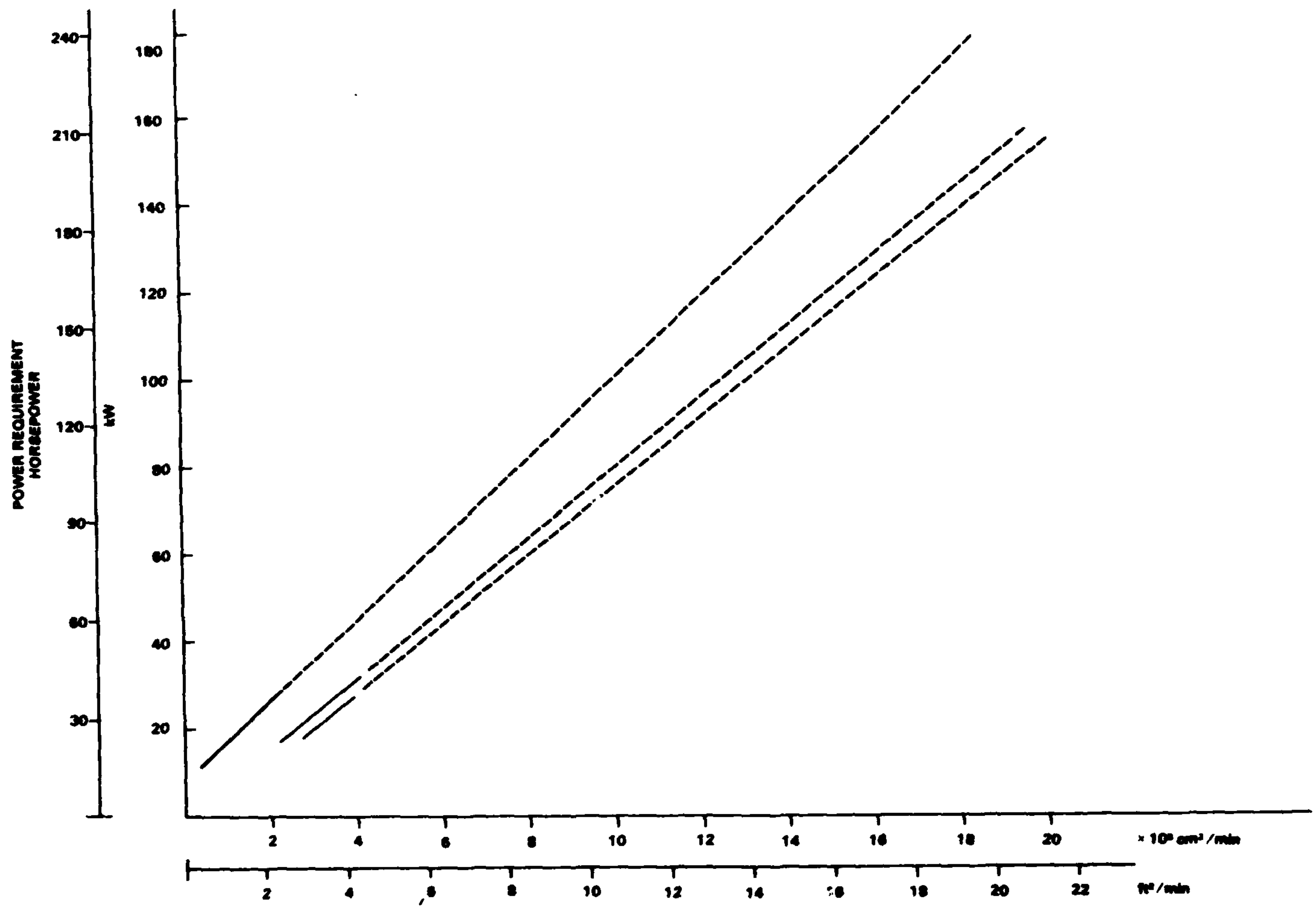


Figure 8. Power vs Cutting Production Rate (Extrapolated From Data at 7-inch Depth of Cut)

(2) Power Requirement Verses Depth of Cut. The Phase I tests (Appendix A) provide some data on the power required for different depths of cut at a constant cutting production rate. Data for two different blades with different metal bonds are shown in Figure 9. The data indicated that for a fixed cutting production rate there is an optimum depth of cut (and therefore a corresponding traverse velocity) which minimizes the power requirement. Insufficient data are available to indicate how this optimum cutting depth varies with higher cutting production rates or with different blade design parameters. Notice that the behavior of the data is similar for the two different metal bonds with the lowest observed power requirement at a 3.5-inch deep cut.

b. Wear Performance

The wear performance of a blade is important in determining the lifetime of the blade, as discussed earlier. The wear performance is significantly affected by the design parameters of the blade. In the Phase I testing data (Appendix A), the large effect of the metal bond on wear performance is clearly demonstrated. The diamond concentration in a segment also has a pronounced effect on wear performance. Figure 10 illustrates this and also shows the dependence of the wear performance on traverse speed. It appears from these data that wear performance stabilizes at lower diamond concentrations and higher traverse speeds.

In general, as the depth of cut is increased for a fixed traverse rate, the power requirements increase. There are several reasons for this behavior. As the cutting surface area is increased the total amount of force the blade must overcome in each revolution is increased. The cutting surface area is proportioned to the length of the perimeter of the blade exposed to the concrete. This length is given by

$$L = r \cos^{-1} (1-d/r)$$

where d is the depth of cut and r is the radius of the blade. (This expression can also be used to compare the cutting surface lengths for blades of different radii and demonstrate that the surface area increases with increasing radius.) Other factors, which affect the power requirement, is the vibration and wobble that occur in making a deep cut. These problems were discussed earlier in Section II in regard to blade tensioning. They are more pronounced for deep cutting with large diameter blades.

The primary wear consideration revealed during testing is the fatigue and subsequent material failure of the blade cores. This problem must be corrected to develop a faster cutting diamond saw blade and the next section will discuss some possible approaches.

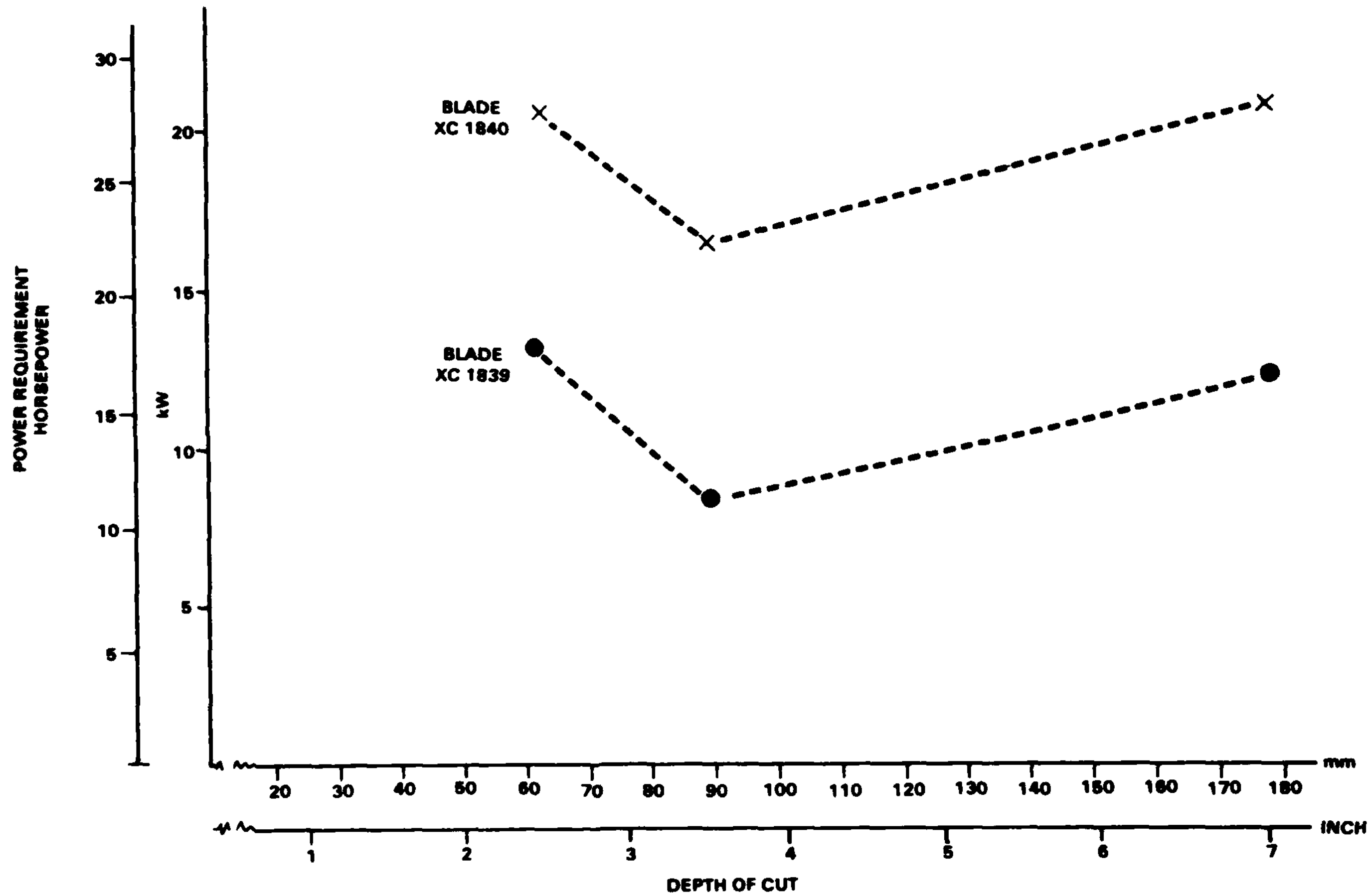


Figure 9. Power Requirements vs Depth-of-Cut for Constant Cutting Production Rate of 580 cm^2/min (0.62 ft^2/min).

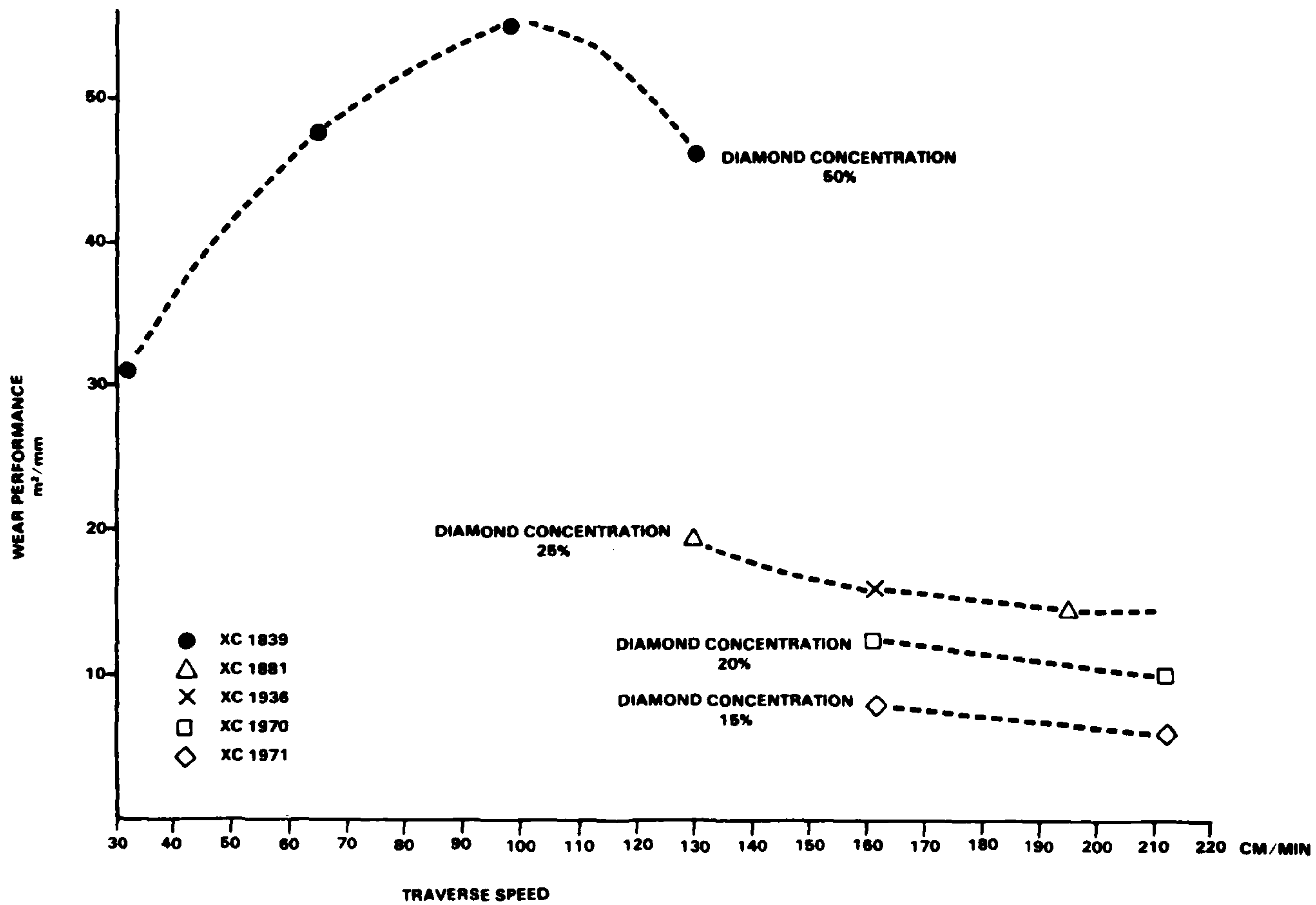


Figure 10. Wear Performance vs Traverse Speed for 177.8 mm Depth of Cut.

SECTION IV

CONCLUSION AND RECOMMENDATIONS

The purpose of this program has been to investigate the feasibility of diamond blade concrete cutting saw systems to meet the requirements, as specified in Section I, for cutting production rates and saw blade lifetime. This section will address program accomplishments and their implications; trade-offs among several alternative diamond saw systems; key technical issues; and recommendations for future programs.

1. CONCLUSIONS AND IMPLICATIONS FROM THE BLADE DEVELOPMENT AND TESTING PROGRAM

The results of this program provided a good indication of the current capabilities of the diamond saw technology and demonstrated substantial improvements in cutting rates by varying blade design parameters. Although the diamond saw technology has certain limitations which are discussed later, it currently has capabilities that are unparalleled by any other concrete cutting technology. It can cut at rates comparable or superior to other technologies and with a quality and alignment of cut which is unmatched. In addition it is one of the few technologies also capable of cutting steel reinforcement rods. Therefore the diamond saw deserves careful examination in any Bomb Damage repair scheme requiring concrete cutting.

A major accomplishment of this program was the identification of an optimum composition of the diamond saw segments for rapid concrete cutting. This type of segment contains a 15-percent diamond concentration of 30/40 mesh strong synthetic diamond crystals in a bronze metal bond matrix. This bronze bond system is much softer than the steel or cobalt bond matrices used in most commercial blades and is consequently subject to more wear and shorter blade lifetime. The wear performance of the segment can be enhanced by increasing the diamond concentration, at the expense of decreasing the cutting performance. The lifetime of a blade will be increased by this change or by increasing the segment height.

A second and very significant implication of the test program is that to achieve higher cutting rates a stronger core must be developed. The core used in the test blades was thicker than those typically used in commercial applications (0.196 inch vs. 0.155 inch). In spite of this slightly heavier duty core, most of the test blades developed gullet cracks when operated at the higher production rates (2.5 to 4.0 ft^2/min.). Operating a diamond saw with a cracked core presents both a safety hazard to the operator and the possibility of damaging the equipment. Several options are available for correcting this problem. First, holes can be drilled at the base of the gullet slots, which will allow stress in that area to be distributed over a larger area. Second, a thicker steel core can be used; however, this would require a correspondingly thicker segment

to insure proper coolant flow and clearance of the core in the kerf. This larger segment width increases the power requirements which could, in turn, increase the stress in the gullets, possibly defeating purpose of the heavier core. This behavior, of course, can only be determined through testing. A third option for a stronger core would be to modify the core itself by using new or different alloy compositions. The cores used in this test program were medium strength low alloy steel. The cores are industrial standards for diamond saw blades and are manufactured in large quantities to meet commercial needs. A special alloy core would therefore require a new R&D effort.

Cutting rates higher than those achieved in this program are obtainable if a stronger core is developed. However, the production goal of 20-30 feet per minute is substantially (5 to 8 times) larger than current cutting rates and does not appear to be obtainable with a single blade saw. Several factors are responsible for this conclusion. Cutting to a 12-inch depth would require a 36-inch diameter blade and a larger portion of the perimeter of this blade would be involved as the cutting surface. This presents significant problems including: cooling of the blade, large stresses within the blade material, and large power requirements. Efficient cooling is difficult because of the larger time each of the segments is in contact with the concrete. The problem is also complicated in regard to providing a proper water flow into the cutting area. If the blade is inadequately cooled, the diamonds will begin to polish, greatly reducing cutting efficiency, and presenting the possibility of melting the metal bond material. As the depth of cut increases the segments on the blade must cut through a longer arch length in the concrete. Because of this the duration a particular section of the blade is stressed and this stress is increased with depth of cut. This can produce fatigue in the blade which can result in cracks. Increasing the traverse speed adds to the problem. In the current blade design developed for this report, the weak element is the blade core. However, even if a core is developed which is strong enough to transmit the requisite power, the segment material will probably fail at cutting rates of 20 ft/min. Another problem associated with deep and rapid cutting is flexing of the diamond saw blade which can result in increased power requirements, poor cut alignment, and increased wear.

2. ALTERNATIVE DIAMOND SAW CONCRETE CUTTING SYSTEMS

Three different diamond saw concrete cutting systems are described below. Evaluation of these systems was made with respect to technical risk, cost risk, and the integration of the system with bomb damage repair operations. Table 6 summarizes this evaluation.

a. A Single-Blade Saw

As stated earlier in this report, a single-blade cutting system does not appear to have the potential of cutting at rates of 20-30 ft^2/min.

TABLE 6. ALTERNATIVE DIAMOND SAW CUTTING SYSTEMS.

System	Blade Design Requirements	Equipment Design Requirements	Advantages/Problems	Technical Risk
Single-Blade Saw	Blade core R&D; Anticipated segment material failure	New saw design with > 190 HP	Requires one to two operators	Infeasible due to material failure
Multiple-Spindle Saw	Increase blade core strength	Blade alignment; Vertical blade movement; Total Power > 200 HP	Requires one to two operators	Low-moderate (primarily blade alignment)
Multiple Saws				
1. Cutting full 12"	Blade core R&D; Possible segment material failure	Power requirement > 40 HP/SAW; May require new design for > 65 HP	Redundancy;Possible use of existing equipment/Multiple ancillary water lines	High (possible material failure)
2. Each with partial cut	Increase blade core strength; possible use of current blade design	Blade alignment control; Power requirement ≈ 40 HP/SAW	Redundancy/Multiple ancillary water lines	Low-Moderate (blade alignment)

because of the high probability of blade material failure. Other aspects of such a system are given below.

As discussed earlier and as shown in Figure 9, the power requirement for a cutting operation is affected by the depth of cut. Based on data from 7-inch deep cuts, a linear relationship was established. Extrapolation indicates that cutting at a 7-inch depth will require power levels at between 190 and 240 horsepower to achieve 20 ft^2/min. Thus cutting at 12-inch depth will require power level well in excess of these. These values may be used for comparison with other cutting systems, if it is assumed that the material problems with the blade can be overcome. It must be noted, however, that the assumed linear relationship may not be valid, particularly when extrapolated so far beyond available data. (Notice the range of the test data in Figure 8 as represented by the solid section of the line.)

If a single-blade cutting system were feasible for bomb damage repair (BDR) operations, it would have certain advantages. Personnel requirements would be small, as only one or two operators would be required. Depending on the coolant flow requirements, such a system could possibly carry its own water supply and thereby be self-contained. However, the coolant flow, for the tests conducted for this program, was approximately 10 gallons per minute and was more than adequate. This would require a 600-gallon tank for an hour's operation; thus, unless the flow rate can be reduced, the system would require some ancillary water supply.

A program attempting to develop a single-blade diamond saw to cut a full 12-inch depth at 20 ft/min would require an extensive investment in research and development efforts at both a high technical and cost risk.

b. A Multiple-Spindle Diamond Saw System

This cutting system has three diamond saw blades operating in tandem. Preliminary design concepts and cost estimates for such a system are being done by Cushion Cut, Inc., and TBG, Inc., as this report is being prepared. Some of the design aspects described here are based on portions of this work.

The first blade in this system would cut the pavement to approximately one-third of its depth. Following in the kerf of the first blade, the second blade would cut to two-thirds depth and the third blade would finish the cut to full depth. Advantages of this system in regard to BDR would be similar to those described for the single-spindle machine. Only one or two operators are required and since this is a single piece of equipment, it minimizes congestion during the repair process. This cutting system, however, will probably require some ancillary equipment to supply cooling water.

Use of three blades instead of one means that each now must meet a production rate of 6.7 ft^2/min to obtain a net rate of 20 ft^2/min. The

power required to drive each of the blades is estimated from Figure 4 to be 60 to 90 horsepower, assuming the validity of the linear relationship. The total power requirement then is approximately 200 to 350 HP.

This system also requires both, that the blade cores be modified from their existing design to remedy the gullet cracking problem, and that there are no materials failures associated with the segments. These blade design requirements all appear feasible as the necessary increase in production rate is relatively small compared to the current achievable 4.0 ft^2/min.

A multiple-spindle cutting design also can possibly exploit the feature shown in Figure 9 of an optimum depth of cut for a fixed cutting rate. This benefit could reduce the total power requirement of the machine. However, the optimum depth could vary substantially with the characteristics of the concrete being cut.

An earlier investigation of the Christensen Model LS-3 Diesel Concrete Saw, which has a similar design concept, indicates there are some technical difficulties with maintaining the alignment of trailing blades in the kerf produced by the leading blade. This problem would be exaggerated at high cutting speeds and, in particular, on a rough debris-laden runway. Certain design considerations are possible to minimize these effects. One is that the system is envisioned as being self-contained (depending on water requirements) on a carriage approximately the size of a pickup truck with sufficient weight and rigidity to reduce lateral blade vibrations. Another measure to help proper blade alignment is to use high precision bearings to support the spindles.

Weight to stabilize the system can be provided by the engine and the water needed for cooling the blades. The coolant water tank on the cutting machine will not be sufficient if a 10-gallon per minute flow rate is required for each blade, as was used in this test program. If a smaller flow rate is not sufficient, then, approximately 1800 gallons of water per hour are required from a water truck or other source.

Other design problems are associated with initiating the cut and with reducing the extent of overcutting at corners into good concrete. Both of these problems can be resolved if the individual blades can be moved vertically. In initiating the cut, the problem is somewhat easier and down feeding all the blades as an array into the concrete would be sufficient. However, reduction of overcutting is more involved. By allowing each blade to move individually as the system reaches the end of the cut, the first two blades can be lifted and the last blade finishes the cut to full depth, only overcutting by its radius. The individual vertical action of each blade will, however, greatly compound the problem of insuring blade alignment. A hydraulic system would be used to raise and lower the blades.

A program to build this concrete cutting system will require the following efforts. First, a research and development effort is needed to investigate and build cores for diamond saw blades which will not crack at the desired cutting rates (6.7-10 ft^2/min. at a depth of approximately 4 inches). This R&D effort would complement the work already conducted for this report. A second stage would then develop a detailed design and fabricate a prototype system. Because the machine will be unlike other diamond saws or standard construction equipment, it will virtually have to be designed from the ground up. A current estimate of the cost of such a program is $750K to $1.5M.

c. Use of Several Single-Blade Saws in Parallel

The premise of this system concept is that the net cutting rate of several diamond saws is the sum of the individual rates of each saw. Such a system becomes feasible when the number of saws required to cut 20 ft^2/min. is so small that it does not hinder the overall RRR effort. The effort would be hindered if the number of saws, ancillary equipment, and equipment operators caused congestion or interference with other RRR tasks. The operation of three to four saws should not present any major adverse effects on other facets of the RRR effort. The multiple-saw system suffers a slight complication over a system utilizing a single machine because of additional lines to a water supply. An advantage of a multiple-saw system is that if one machine becomes inoperable the cutting process can still continue, although at a slower rate. Also, if a saw becomes jammed, from expansion or stress in the concrete closing the slot on the blade, the multiple-saw system can cut the jammed saw free.

There are two different concepts for the use of the multiple-saw system. One concept would be to have each of the saws cutting to full depth (12 inches) and working on different segments of the total desired cutting path. The second concept would have the saws working in tandem, each one only cutting a part of the full depth. These two concepts have certain aspects in common with two systems already discussed. However, the cutting production rate required of each blade can be lower. For a four-saw system, the rate required of each blade is 5 ft^2/min. to produce a net system cutting rate of 20 ft^2/min.

The first concept identified above, multiple saws making full depth cuts, has many of the problems of the single-blade system which does not appear feasible. These problems stem from the difficulties in making a 12-inch deep cut which were discussed earlier. It has been estimated that the current diamond saw capabilities for cutting at a 12-inch depth is at best 2 linear feet per minute. The multiple-saw system requires a traverse speed of 5 ft^2/min. This is felt to be doubtful yet feasible. The key issues in developing this system are (1) fabricating blade cores of sufficient strength to withstand the forces required to cut at 5 ft/min and (2) determining if the material strength of the segments are sufficient. Because a 12-inch deep cut requires more power than one 7 inches deep, Figure 4 can be used to obtain a lower limit on the power

requirement for each saw. For a 5 ft^2/min production rate, the power required is 40 to 70 horsepower. Commercially available diamond saws provide up to approximately 65 horsepower and cost between $7,000 and $8,000. If the power required for this multiple-saw system lies in the range for the commercial saws, then it would be an attractive system.

The other concept identified above for using multiple saws in tandem is closely analogous to the multiple-spindle concept discussed earlier. This system has an advantage compared to the other proposed systems in that the blades which were developed for this program come very close to meeting the needed cutting production rate (5 ft^2/min). Only a small modification to the existing optimum blade would be required and this would be in regard to strengthening the core. The major technical difficulty with this system is the same as described for the multiple-spindle machine above. This difficulty is aligning the blades in the kerf cut by previous blades. This problem is not insurmountable but could require the design and development of a new saw incorporating some alignment mechanism and having the same stability requirements as the multiple-spindle system. The technical risk associated with aligning the blades is possibly less severe for the multiple separate saw system than the multiple-spindle system. For the multiple separate saw system there is no mechanical coupling constraining the action of the individual blades as there is with the multiple-spindle system. It may therefore be possible to more readily correct misalignment problems with multiple saws. Testing is required to determine the capabilities of a multiple-saw system using off-the-shelf saws. If it is not possible to meet alighment requirements with the existing equipment then a new saw would have to be developed. Depending on the stability requirements, the cost of several of these improved saws could be greater than developing the multiple-spindle system.

3. MISCELLANEOUS TECHNICAL ISSUES

Several technical issues remain in regard to diamond saws. The first of these pertains to the effect of the concrete on the cutting performance. Performance of a saw of given horsepower, can vary dramatically for different types of concretes. The major differences can be attributed to the hardness of the aggregate. Tests performed for this report were conducted in a concrete of medium sawability, containing granite aggregate. Members of the testing laboratory estimated that cutting rates could double if cutting was conducted in a concrete of soft sawability, containing certain limestone aggregates. Much of the concrete used in Europe contains an aggregate harder than granite, such as flints. The cutting rates in these types of concrete are expected to be slower, although quantitatively this can only be established by testing. Wear of the diamond saw blade is also increased in harder concrete. Composite pavements with an asphalt upper layer will also increase the wear on the blade; however, the cutting rate in asphalt is much higher than the softest concrete. This increased wear is expected to be a lesser problem for cutting systems utilizing multiple blades as the extra wear is distributed over all the blades.

The possible jamming of a diamond saw by a slot closing on the blade can have a major effect on the bomb damage repair effort. Possible causes of this problem are the thermal expansion of the concrete, or stress in the concrete caused by the bomb damage itself. The potential of these to affect cutting operations can only be assessed by thorough testing.

4. RECOMMENDATIONS

It is recommended that a program be undertaken to develop a stronger diamond saw blade core and to test the resulting diamond saw blades utilizing optimum bond and diamond characteristics cited in this report. Methods for increasing the strength of the blade would include: varying the gullet design such as by drilling gullet holes; increasing the core thickness; changing the alloy composition of the core by initially looking at more readily available commercial materials and then, if necessary, looking at specially tailored alloys. Testing associated with this program should examine cutting performance at 3-, 4-, 5-, 7-, and 12-inch depth of cuts at various cutting rates. This program will allow a flexibility because it supports both the multiple-spindle system and the multiple-saw systems. Depending on the cutting rates which can be obtained for 12-inch deep cuts and the associated power requirement, the option of a multiple-spindle system or a system of multiple saws cutting to full depth can be resolved. Only a marked improvement in blade performance at 12-inch depth would allow the multiple saws cutting to full depth to be feasible. On the other hand, the use of a multiple-spindle system appears to be feasible with only minor improvements in blade performance, assuming the problems with blade alignments can be resolved.

APPENDIX A
PHASE I TEST REPORT

The material contained in this test report has been provided by Cushion Cut based on tests conducted by an independent test laboratory mutually agreed upon by Cushion Cut, BDM and AFESC.

1. INTRODUCTION

Four 600 mm (24-inch) diameter concrete saw blades were evaluated for Cushion Cut. Each of the test blades employed a different bond system, and the objective of this evaluation was to determine the maximum deep sawing cutting rates that could be obtained with these special Cushion Cut blades designed for BDM. Tests were completed in December 1981.

2. DESCRIPTION OF TESTS

The blades were tested in 254 mm (10-inch) thick, cured concrete with granite aggregate slabs. A test blade rotation procedure has been developed where cuts with each blade are completed in each concrete test slab. The number of test slabs consumed during any evaluation is determined by the number of test blades being evaluated. The blade rotation procedure ensures that any inconsistencies within the test slabs are normalized.

The saw machine is a 37.3 kW (50 hp), electric Patch-Wegner saw, fully automated and programmable. The dimension characteristics of the test blades and individual blade data are continued in Table A-1. The test procedure is described below. Concrete specifications are given in Table A-2.

A blade test consisted of sawing sufficient concrete with each test blade to generate at least .08 mm (0.003 inch) of blade radii wear. Wear performance was calculated by dividing the amount of concrete sawn (square meters) by the blade radii wear (millimeters). The average power requirement for each blade was determined with a recording integrating watt meter. A microscopic examination of six segments on a blade was also performed after each test to analyze the diamond and bond wear characteristics.

3. TEST PROCEDURE

Before any tests were started, each blade was conditioned in cured concrete with granite aggregate to wear all segments to a representative, reproducible cutting surface. Each saw blade was then measured and run at the test conditions.

TABLE A-1. BLADE DESCRIPTION.

Blade Number	B40044-1 XC 1839	B40045-1 XC 1840	B40046-1 XC 1841	B40047-1 XC 1842
Dimension Characteristics:				
Blade Diameter	616 mm	616 mm	616 mm	616 mm
Blade Core Thickness	4.97 mm	4.97 mm	4.97 mm	4.97 mm
Segment Height	6.35 mm	6.35 mm	6.35 mm	7.14 mm
Segment Thickness (Nominal)	7.77 mm	7.77 mm	7.77 mm	7.77 mm
Segment Length	55.2 mm	54.0 mm	54.0 mm	54.0 mm
Segments/Blade	33	33	33	33
Blade Rim Length	1821 mm	1781 mm	1781 mm	1781 mm
Individual Blade Data:				
Hardness Rockwell B	55	94	102	122

TABLE A-2. SPECIFICATIONS FOR CONCRETE TEST SLAB.

Designation	Cured Concrete w/Granite Aggregate
Slab Size	1.2 m x 1.2 m x 25.4 cm
Slab Composition:	
Type 3A Cement	1 part by weight
Concrete Sand	1.9 parts by weight
Mountain Stone Granite Aggregate	2.8 parts by weight
Water/Cement Ratio	0.47 by weight
Concrete Properties:	
ASTM Slump Value	2 inches maximum
28th Day Compressive Strength	6000 pounds per square inch

The power required by the saw blade when cutting was measured, and the average value was recorded. After each blade was tested, the radii wear was measured with a precision blade-measuring device to the nearest .0025 mm. The wear performance of each blade was calculated by dividing the amount of concrete sawn by the blade radii wear. A microscopic examination of six segments on the blade was also performed after each test to analyze the diamond and bond wear characteristics.

$$\text{Wear Performance} = \frac{\text{amount of material sawn}}{\text{radii wear}}$$

4. RESULTS

The wear performance characteristics and average power required are shown graphically in Figures A-1, A-2, and A-3. Individual blade data and the sawing conditions are summarized in Tables A-3 through A-15.

Test 1 (Figure A-1, Tables A-3, A-4, and A-5) was completed at the standard sawing conditions of 63.5 mm (2.5 in) depth of cut x 91.4 cm/min (3 ft/min) traverse rate for a cutting rate of 580 cm^2/min (3 ft/min). Blade XC 1839 required the least power and had the lowest wear performance.

Test 2 (Tables A-4, A-6, and A-7) was completed at a depth of cut of 88.9 mm (3.5 inches) and a traverse rate of 65.3 cm/min (2.1 ft/min) for a cutting rate of 580 cm^2/min (0.62 ft^2/min). Blade XC 1839 required the least power and had the lowest wear performance.

Test 3 (Figure A-2, Tables A-4, A-8, and A-9) was completed at a depth of cut of 177.8 mm (7 inches) (the goal for the evaluation) and the traverse rate was reduced to 32.8 cm/min (1 ft/min) for a cutting rate of 580 cm^2/min (0.62 ft^2/min). Blade XC 1839 required the least power and had the lowest wear performance.

Blades XC 1840, XC 1841, and XC 1842 would not cut at any of the higher cutting rates investigated in this evaluation. The blades either stalled the spindle motor or began to flex during the cut.

Additional tests (No. 4, No. 5, and No. 6) with blade XC 1839 were completed at a depth of cut of 177.8 mm. The traverse rate was increased in each test for resulting cutting rates of 1160 cm^2/min (1.25 ft^2/min), 1740 cm^2/min (1.87 ft^2/min), and 2320 cm^2/min (2.5 ft^2/min). The results of these tests are shown graphically in Figure A-3, and individual blade data and the sawing conditions are summarized in Tables A-10 through A-15. The wear performance of Blade XC 1839 seemed to stabilize at the higher cutting rates. The power required at the different cutting rates continued to increase; at the 2320 cm^2/min cutting rate, Blade XC 1839 stalled several times.

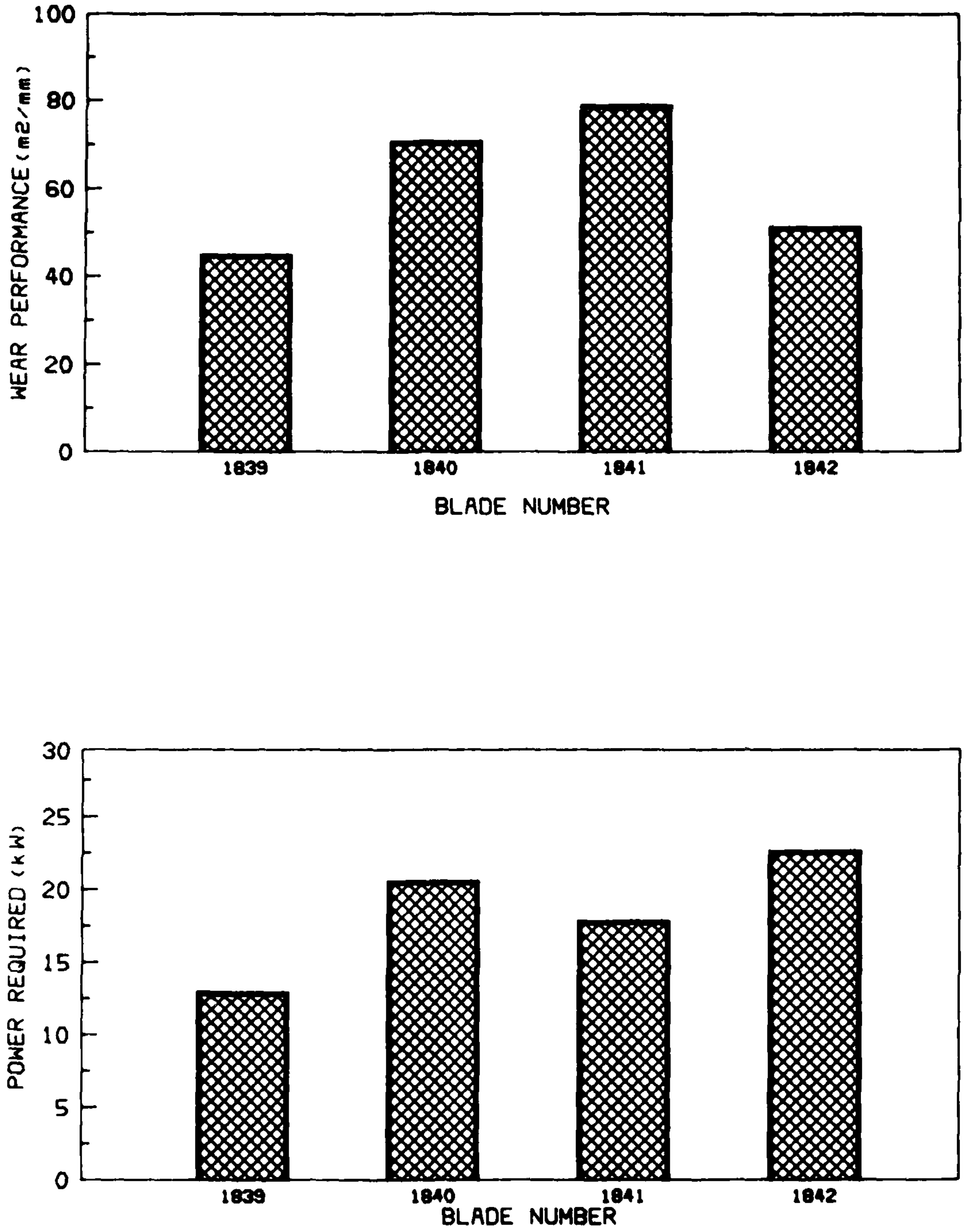
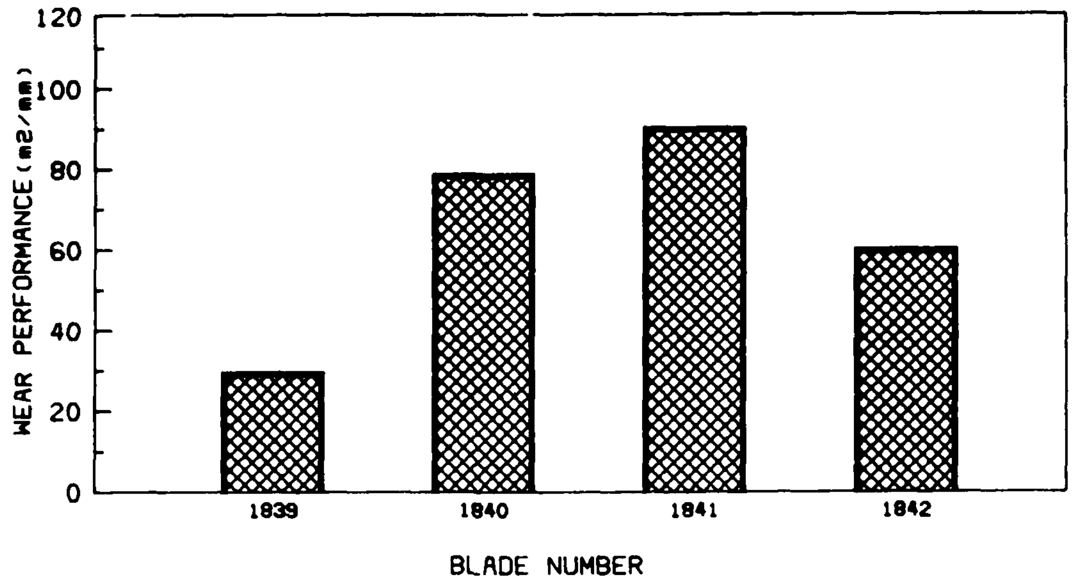


Figure A-1. Wear Performance and Power Required in Cured Concrete at 63.5 mm Depth of Cut - 580-cm^2/min.



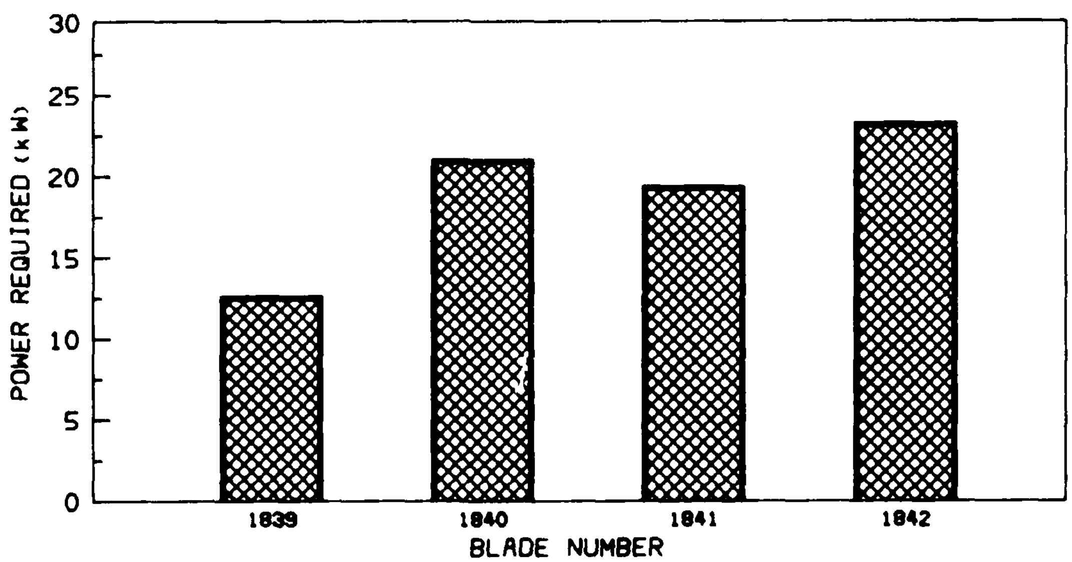
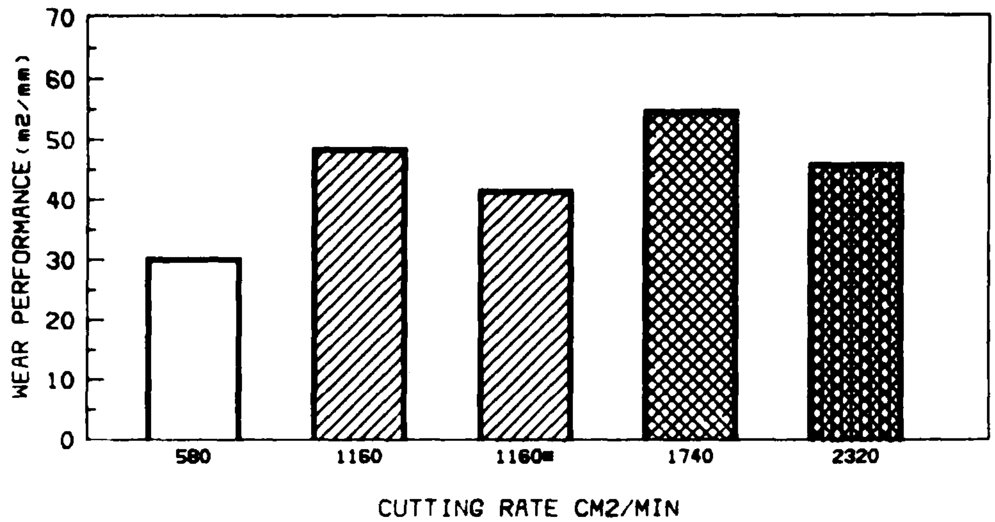


Figure A-2. Wear Performance and Power Required in Cured Concrete at 177.8 mm Depth of Cut - 580-cm^2/min.



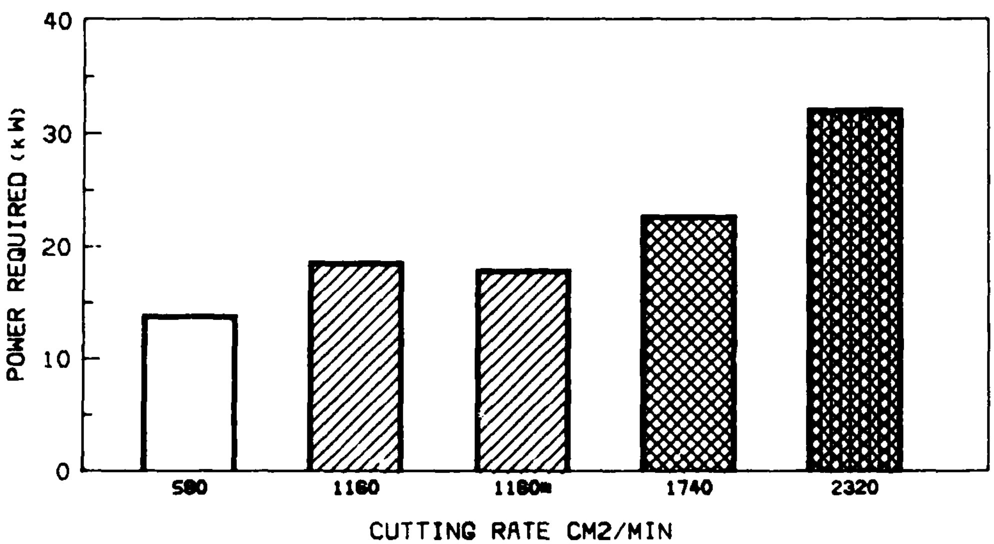


Figure A-3. Blade 1839 - Wear Performance and Power Required in Cured Concrete at 177.8 mm Depth of Cut - Various Cutting Rates.

TABLE A-3. BLADE PERFORMANCE DATA,
TEST NO. 1 - 63.5 MM DEPTH OF CUT-580 cm^2/min.

Blade Number	Average Power (kW)	Wear Performance (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1839	13.1	44.7	48	14	37	Fair	60
XC 1840	20.7	71.1	57	24	20	Fair	63
XC 1841	18.0	78.2	54	18	28	Fair	68
XC 1842	22.9	52.6	50	30	20	Fair	58

* Whole Crushed Popout

TABLE A-4. TEST SAWING CONDITIONS WITH 37.3 kW PATCH-WEGNER ELECTRIC MOTOR.

Parameter	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Downfeed (plunge, down cut)	63.5 mm	88.9 mm	177.8 mm	177.8 mm	177.8 mm	177.8 mm
Traverse Rate	91.4 cm/min	65.3 min	32.8 cm/min	65.3 cm/min	98.0 cm/min	130.6 cm/min
Cutting Rate	580 cm^2/min	580 cm^2/min	580 cm^2/min	1160 cm^2/min	1740 cm^2/min	2320 cm^2/min
Arbor Speed	1450 RPM	1450 RPM	1450 RPM	1450 RPM	1450 RPM	1450 RPM
Blade Surface Speed	46.3 m/sec	46.3 m/sec	46.3 m/sec	46.3 m/sec	46.3 m/sec	46.3 m/sec
Coolant Flow Rate	13 liters/min	13 liters/min	13 liters/min	13 liters/min	13 liters/min	13 liters/min

TABLE A-5. DATA TEST NO. 1.

Blade Number	Amount Sawn (m2)	Radii Wear (mm)	Thickness Wear (mm)
XC 1839	8.1	0.180	0.025
XC 1840	7.4	0.140	0.020
XC 1841	7.9	0.102	0.015
XC 1842	5.6	0.107	0.028

TABLE A-6. BLADE PERFORMANCE DATA
TEST NO. 2 - 88.9 mm DEPTH OF CUT - 580 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf. (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1839	8.6	38.8	58	5	37	Good	63
XC 1840	16.7	83.0	70	7	23	Good	64
XC 1841	16.9	95.5	58	6	36	Good	75
XC 1842	19.4	83.7	57	12	31	Good	60

* Whole Crushed Popout

TABLE A-7. DATA TEST NO. 2.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)
XC 1839	7.6	.196	.013
XC 1840	7.6	.091	.008
XC 1841	7.5	.079	.013
XC 1842	7.7	.091	.013

TABLE A-8. BLADE PERFORMANCE DATA
TEST NO. 3 - 177.8 mm DEPTH CUT - 580 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1839	12.6	31.1	53	6	40	Good	57
XC 1840	21.0	78.6	62	12	26	Good	70
XC 1841	19.4	90.5	62	5	33	Good	74
XC 1842	23.3	61.0	57	17	26	Good	66

* Whole   Crushed   Popout

TABLE A-9. DATA TEST NO. 3.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)
XC 1839	7.6	.244	.015
XC 1840	7.6	.097	.010
XC 1841	7.6	.084	.003
XC 1842	7.6	.124	.003

TABLE A-10. BLADE PERFORMANCE DATA
TEST NO. 4 - 177.8 mm DEPTH OF CUT - 1160 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1839	18.4	47.8	52	7	41	Good	56
XC 1839 (retest)	17.5	42.1	57	7	36	Good	57

* Whole Crushed Popout

TABLE A-11. DATA TEST NO. 4.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)
XC 1839	7.5	.157	.008
XC 1839 (retest)	7.6	.180	.028

TABLE A-12. BLADE PERFORMANCE DATA
TEST NO. 5 - 177.8 mm DEPTH OF CUT - 1740 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1839	23.2	55.3	57	9	34	Good	58

* Whole Crushed Popout

TABLE A-13. DATA TEST NO. 5.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)
XC 1839	7.6	.137	.028

TABLE A-14. BLADE PERFORMANCE DATA
TEST NO. 6 - 177.8 mm DEPTH OF CUT - 2320 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1839	32.4	46.7	54	12	33	Fair	60

* Whole Crushed Popout

TABLE A-15. DATA TEST NO. 6.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)
XC 1839	7.6	.163	.033

5. RECOMMENDATIONS

The following recommendations are made based on the results of the first phase of testing:

- Complete additional tests with blades based on XC 1839 bond.
- Investigate the use of coarser mesh abrasive with XC 1839 bond.
- Investigate lower concentration blades based on the XC 1839 bond.

APPENDIX B

PHASE II TEST REPORT

The material contained in this test report has been provided by Cushion Cut based on tests conducted by an independent test laboratory mutually agreed upon by Cushion Cut, BDM, and AFESC.

1. INTRODUCTION

Three 600 mm (24 in) diameter concrete saw blades were evaluated for Cushion Cut. The objective of this evaluation was to determine the maximum deep sawing cutting rates that could be obtained with these special Cushion Cut blades designed for runway sawing. Tests were completed in April 1982.

2. DESCRIPTION OF TESTS

The blades were tested in 254 mm (10-inch) thick, cured concrete slabs with granite aggregate. A test blade rotation procedure has been developed where cuts with each blade are completed in each concrete test slab. The number of test slabs consumed during any evaluation is determined by the number of test blades being evaluated. The blade rotation procedure insures that any inconsistencies within the test slabs are normalized.

The saw machine is a 37.3 kW (50 hp), electric Patch-Wegner saw, fully automated and programmable. The dimension characteristics of the test blades and individual blade data are contained in Table B-1. The test procedure and concrete specifications are given in Appendix A, paragraph 3.

A blade test consisted of sawing sufficient concrete with each test blade to generate at least .4 mm (0.016 inches) of blade radii wear. Wear performance was calculated by dividing the amount of concrete sawn (square meters) by the blade radii wear (millimeters). The average power requirement for each blade was determined with a recording integrating watt meter. A microscopic examination of six segments on a blade was also performed after each test to analyze the diamond and bond wear characteristics.

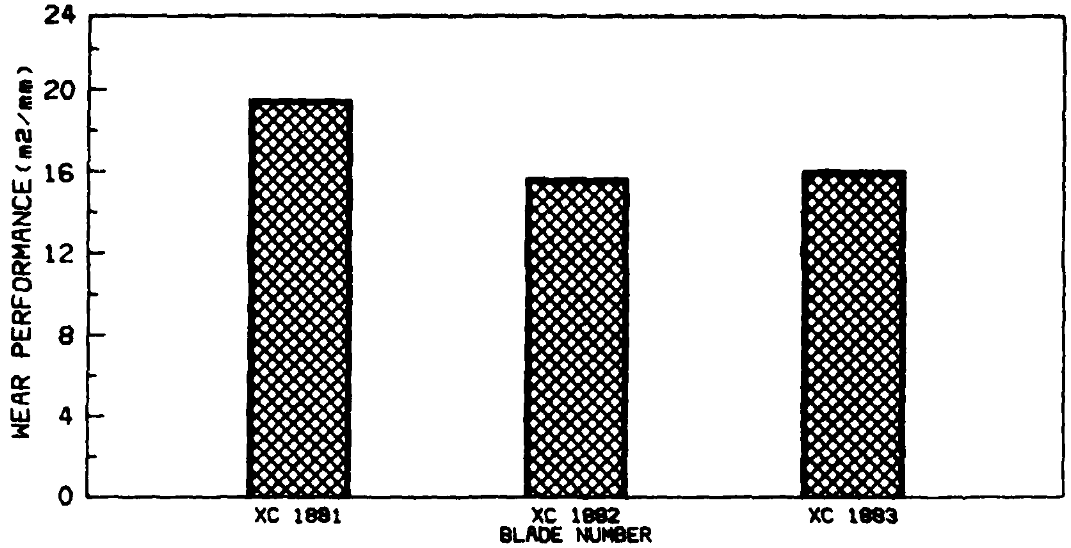
3. RESULTS

The wear performance characteristics and average power required are shown graphically in Figures B-1 and B-2. Individual blade data and the sawing conditions are summarized in Tables B-2 to B-6.

Test 1 (Figure B-1, Tables B-2, B-3 and B-4) was completed at a depth of cut of 177.8 mm (7 inches) and a traverse rate of 130.6 cm/min (4.28 ft/min) for a cutting rate of 2320 cm^2/min (2.5 ft^2/min). Blade XC 1883 developed gullet cracks after the Test 1 pretest and Blade XC 1882 developed gullet cracks during Test 1. The cracks did not increase in size or number during the second test. The blades required nearly equal power; Blade XC 1881 was

TABLE B-1. BLADE DESCRIPTION.

Blade Number	B41352-1 XC 1881	B41353-1 XC 1882	B41354-1 XC 1883
Dimension Characteristics:			
Blade Diameter	614 mm	614 mm	614 mm
Blade Core Thickness	4.97 mm	4.97 mm	4.97 mm
Segment Height	5.16 mm	5.16 mm	5.16 mm
Segment Thickness (nominal)	6.22 mm	6.22 mm	6.22 mm
Segment Length	54.0 mm	54.0 mm	54.0 mm
Segments/Blade	33	33	33
Blade Rim Length	1781 mm	1781 mm	1781 mm
Individual Blade Data:			
Diamond Type	Synthetic	Synthetic	Synthetic
Mesh Size	40/50 est.	40/50 est	40/50 est.
Concentration	17 est.	17 est.	17 est.
Hardness Rockwell B	57	58	56



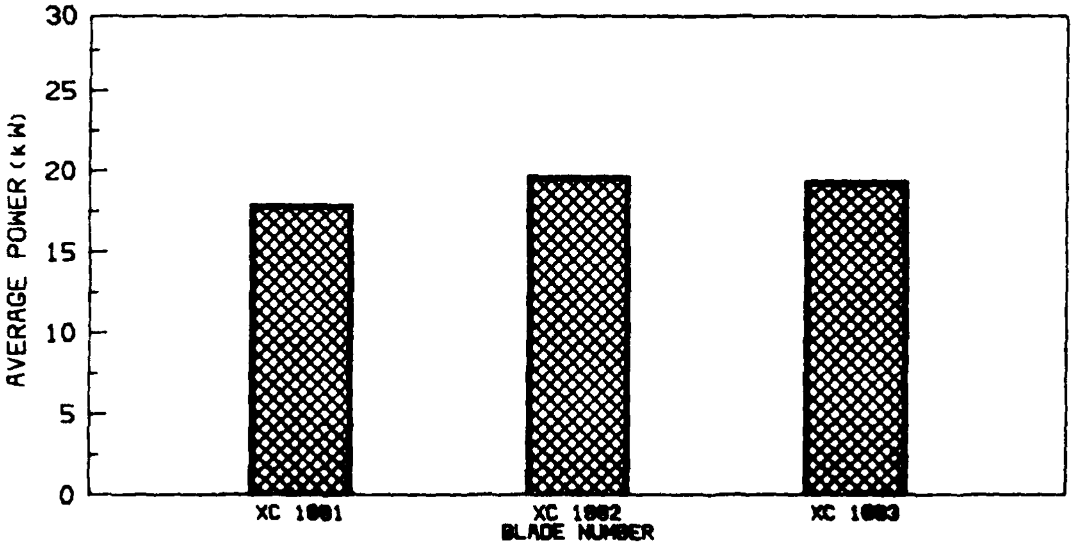
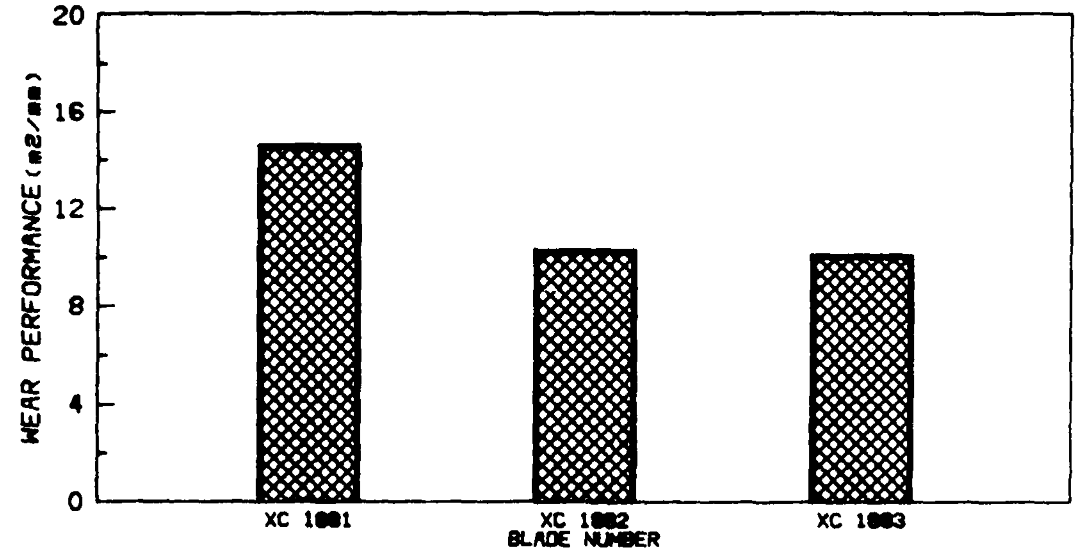


Figure B-1. Test 1 at 2320 cm^2/min.



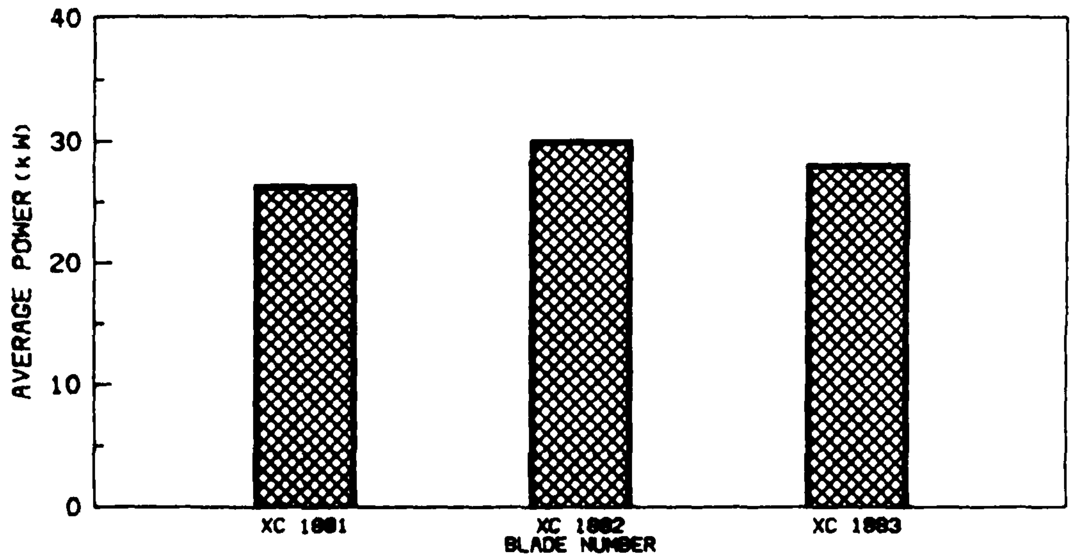


Figure B-2. Test 2 at 3481 cm^2/min.

TABLE B-2. SAWING CONDITIONS USING
A PATCH-WEGNER 37.3 kW ELECTRIC SAW.

PARAMETER	TEST 1	TEST 2
Downfeed	177.8 mm	177.8 mm
Traverse Rate	130.6 cm/min	195.8 cm/min
Cutting Rate	2320 cm^2/min	3481 cm^2/min
Arbor Speed	1450 RPM	1450 RPM
Blade Surface Speed	46.6 m/sec	46.6 m/sec
Coolant Flow Rate	38 liters/min	38 liters/min

TABLE B-3. BLADE PERFORMANCE DATA
TEST NO. 1 AT 2320 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1881	18.0	19.3	55	7	38	Good	33
XC 1882	19.4	15.4	40	30	30	Fair	32
XC 1883	19.0	16.0	41	25	34	Fair	30

*Whole Crushed Popout

TABLE B-4. DATA TEST NO. 1.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)	Remarks
XC 1881	8.7	.452	.056	
XC 1882	8.6	.561	.033	Gullet cracks visible after test
XC 1883	8.7	.544	.046	Gullet cracks visible after pretest

TABLE B-5. BLADE PERFORMANCE DATA
TEST NO. 2 AT 3481 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf. (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1881	26.4	14.7	48	18	34	Fair	31
XC 1882	29.7	10.4	37	32	31	Fair	29
XC 1883	28.1	10.3	48	25	27	Fair	35

* Whole Crushed Popout

TABLE B-6. DATA TEST NO. 2.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)
XC 1881	6.5	.445	.071
XC 1882	6.5	.625	.064
XC 1883	6.5	.635	.061

slightly lower. Blade XC 1881 had the highest wear performance and Blades XC 1882 and XC 1883 were nearly equal in wear performance and were about 20 percent lower than XC 1881. Blade XC 1881 had the highest percent of whole crystals and the lowest percent of crushed crystals. Blade XC 1881 also had the highest percent of popouts.

Test 2 (Figure B-2, Tables B-2, B-5 and B-6) was completed at a depth of cut 177.8 mm (7 inches) and a traverse rate of 195.8 cm/min (6.42 ft/min) for a cutting rate of 3481 cm^2/min (3.75 ft^2/min). Blade XC 1881 required the lowest power; however, all three blades required nearly equal power. Both Blades XC 1882 and XC 1883 stalled at least once at the Test 2 conditions. Blade XC 1881 had the highest wear performance; Blades XC 1882 and XC 1883 were equal in wear performance and were about 30 percent lower than Blade XC 1881. Blade XC 1881 had the lowest percent of crushed crystals and a slightly higher percent of popout crystals.

The highest cutting rate that could be obtained in the first phase testing of the special blades (Appendix A) was 2320 cm^2/min (2.5 ft^2/min) and required over 32 kW (43 HP) of power. The first test in this evaluation was completed at 2320 cm^2/min and the power required was in the 18 to 19.4 kW (24-26 HP) range, a reduction of 40 percent in required power. The second test in this evaluation was completed at 3481 cm^2/min, a 50 percent increase in cutting rate. The average power required at 3481 cm^2/min ranged from 26.4 to 29.7 kW (35.4-39.8 HP), about the maximum power available with the Patch-Wegner saw. The 3481 cm^2/min (3.75 ft^2/min) cutting rate is six times the standard test cutting rate for cured concrete.

The three blades tested in this evaluation were manufactured using the recommended bond system from the first phase testing. The test blades contain a significantly lower concentration of abrasive, about half the number of crystal sites per square centimeter on the cutting surface. The dimension characteristics of the test blades differ from the blades tested under Phase I; the segment height is lower and the segment thickness has been reduced. The lower concentration of abrasive and the reduction in the segment thickness results in a more free cutting blade.

4. RECOMMENDATIONS

From the results of this phase of testing it is recommended the that use of coarser mesh abrasive be investigated.

APPENDIX C

PHASE III TEST REPORT

The material contained in this test report has been provided by Cushion Cut based on tests conducted by an independent test laboratory mutually agreed upon by Cushion Cut, BDM, and AFESC.

1. INTRODUCTION

Three 619 mm (24-inch) diameter concrete saw blades were evaluated for Cushion Cut. The objective of this evaluation was to determine the maximum deep sawing cutting rates that could be obtained with these special Cushion Cut blades designed for runway sawing. Tests were completed the by 30 June 1982.

2. DESCRIPTION OF TESTS

The blades were tested in 254 mm (10-inch thick, cured concrete slabs with granite aggregate. A test blade rotation procedure has been developed where cuts with each blade are completed in each concrete test slab. The number of test slabs consumed during any evaluation is determined by the number of test blades being evaluated. The blade rotation procedure insures that any inconsistencies within the test slabs are normalized.

The saw machine is a 37.3 kW (50 hp), electric Patch-Wagner saw, fully automated and programmable. The dimension characteristics of the test blades and individual blade data are contained in Table C-1. The test procedure and concrete specifications are given in Appendix A.

A blade test consisted of sawing sufficient concrete with each test blade to generate at least .5 mm (0.02 in) of blade radii wear. Wear performance was calculated by dividing the amount of concrete sawn (square meters) by the blade radii wear (millimeters). The average power requirement for each blade was determined with a recording integrating watt meter. A microscopic examination of six segments on a blade was also performed after each test to analyze the diamond and bond wear characteristics.

3. RESULTS

The wear performance characteristics and average power required are shown graphically in Figure C-1. Individual blade data and the sawing conditions are summarized in Tables C-2 to C-4.

The blades were tested at a depth of cut of 177.8 mm (7 inches) and a traverse rate of 163.3 cm/min (5.36 ft/min) for a cutting rate of 2903 cm^2/min (3.12 ft^2/min). The wear performance of the test blades is essentially equal. Blades XC 1935 and XC 1936 are similar in average power required (25.9 kW and 25.2 kW); however, Blade XC 1937 required significantly higher power (16 percent to 19 percent higher). Blade XC 1937 was on the verge of stalling throughout the test.

TABLE C-1. BLADE DESCRIPTION.

Blade Number	43229-1 XC 1935	B43230-1 XC 1936	B43231-1 XC 1937
Dimension Characteristics:			
Blade Diameter	619 mm	619 mm	619 mm
Blade Core Thickness	4.97 mm	4.97 mm	4.97 mm
Segment Height	8.73 mm	8.73 mm	8.73 mm
Segment Thickness (nominal)	6.22 mm	6.22 mm	6.22 mm
Segment Length	54.0 mm	54.0 mm	54.0 mm
Segments/Blade	33	33	33
Blade Rim Length	1781 mm	1781 mm	1781 mm
Individual Blade Data:			
Diamond Type	Synthetic	Synthetic	Synthetic
Mesh Size	30/40 est.	40/50 est.	50/60 est.
Concentration	15 est.	15 est.	15 est.
Hardness Rockwell B	60	61	62

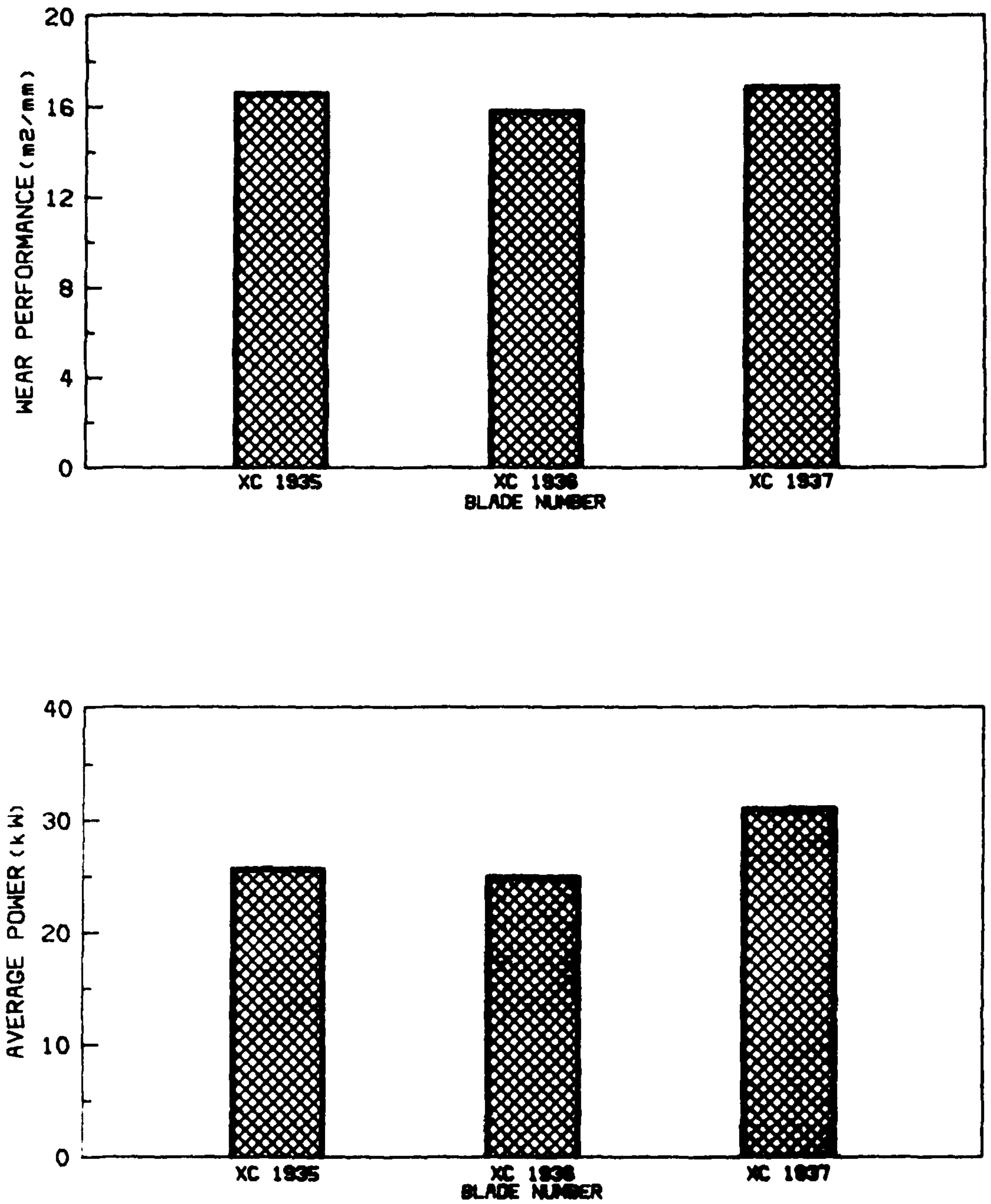


Figure C-1. Test 1 at 2903 cm^2/min.

TABLE C-2. SAWING CONDITIONS USING
A PATCH-WEGNER 37.3 kW ELECTRIC SAW.

PARAMETER	TEST 1
Downfeed	177.8 mm
Traverse Rate	163.3 cm/min
Cutting Rate	2903 cm^2/min
Arbor Speed	1450 RPM
Blade Surface Speed	47 m/sec
Coolant Flow Rate	38 liters/min

TABLE C-3. BLADE PERFORMANCE DATA
TEST NO. 1 AT 2903 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	# Crystals/ cm^2
XC 1935	25.9	16.5	39	29	32	Fair	23
XC 1936	25.2	15.9	40	16	44	Fair	32
XC 1937	31.0	16.8	55	11	34	Fair	57

* Whole Crushed Popout

TABLE C-4. DATA TEST NO. 1.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)	Remarks
XC 1935	9.6	.579	.023	Gullet cracks visible after test
XC 1936	9.5	.599	.036	Gullet cracks visible after test
XC 1937	9.5	.566	.010	Gullet cracks visible after test

Blade XC 1935 had the lowest number of crystal sites per square centimeter and, based on the visual examination of the cutting surface, contains a coarser mesh diamond. Blade XC 1936 had a number of crystal sites per square centimeter similar to the blades tested in Phase II of the program (Appendix B). Blade XC 1937 had the highest number of crystal sites per square centimeter and the visual examination of the cutting surface indicates a fine mesh size of diamond.

The three test blades developed gullet cracks during the test at 2903 cm^2/min (3.12 ft^2/min). Because of the gullet cracks, no attempt was made to test the blades at a higher cutting rate.

APPENDIX D

PHASE IV TEST REPORT

The material contained in this test report has been provided by Cushion Cut based on tests conducted by an independent test laboratory mutually agreed upon by Cushion Cut, BDM, and AFESC.

1. INTRODUCTION

Three 619 mm (24-inch) diameter concrete saw blades were evaluated for Cushion Cut. The objective of this evaluation was to determine the maximum deep sawing cutting rates that could be obtained with these special Cushion Cut blades designed for runway sawing. Tests were completed the end of August 1982.

2. DESCRIPTION OF TESTS

The blades were tested in 254 mm (10-inch) thick, cured concrete slabs with granite aggregate. A test blade rotation procedure has been developed where cuts with each blade are completed in each concrete test slab. The number of test slabs consumed during any evaluation is determined by the number of test blades being evaluated. The blade rotation procedure insures that any inconsistencies within the test slabs are normalized.

The saw machine is a 37.3 kW (50 hp) electric Patch-Wegner saw, fully automated and programmable. The dimension characteristics of the test blades and individual blade data are contained in Table D-1. The test procedure and concrete specifications are given in Appendix A.

A blade test consisted of sawing sufficient concrete with each test blade to generate at least .4 mm (0.016 inch) of blade radii wear. Wear performance was calculated by dividing the amount of concrete sawn (square meters) by the blade radii wear (millimeters). The average power requirement for each blade was determined with a recording integrating watt meter. A microscopic examination of six segments on a blade was also performed after each test to analyze the diamond and bond wear characteristics.

3. RESULTS

The wear performance characteristics and average power required are shown graphically in Figures D-1 and D-2. Individual blade data and the sawing conditions are summarized in Tables D-2 to D-6.

Blade XC 1881 developed gullet cracks during the initial pretest and testing of this blade was terminated.

TABLE D-1. BLADE DESCRIPTION.

Blade Number	XC 1881	XC 1970	XC 1971
Dimension Characteristics:			
Blade Diameter	614 mm	619 mm	619 mm
Blade Core Thickness	4.9 mm	4.9 mm	4.9 mm
Segment Height	5.6 mm	8.7 mm	8.7 mm
Segment Thickness (nominal)	6.2 mm	6.2 mm	6.2 mm
Segment Length	54.4 mm	54.8 mm	54.8 mm
Segments/Blade	33	33	33
Blade Rim Length	1.794 m	1.807 m	1.807 m
Individual Blade Data:			
Diamond Type	Synthetic	Synthetic	Synthetic
Hardness Rockwell B	52	56	57

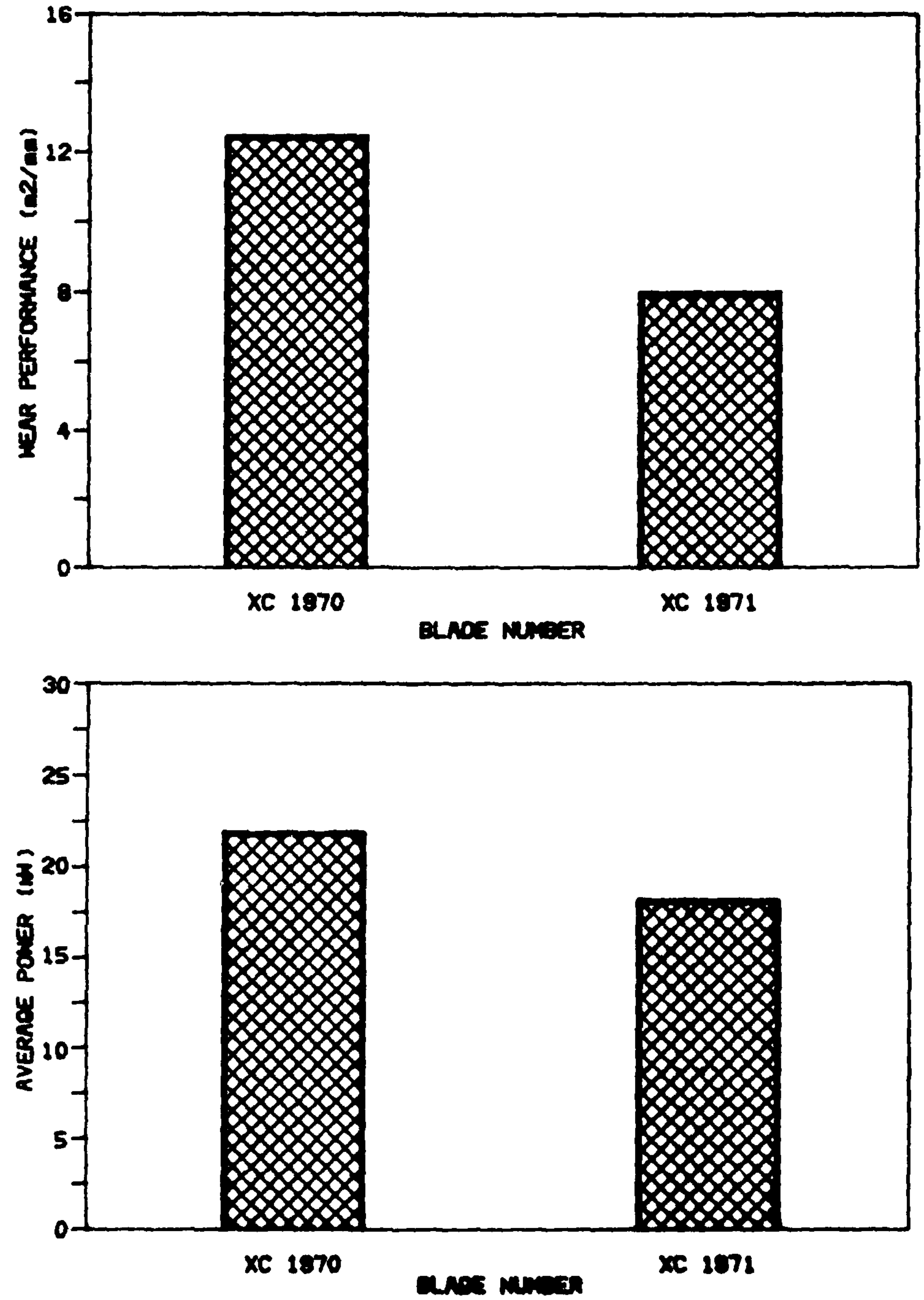
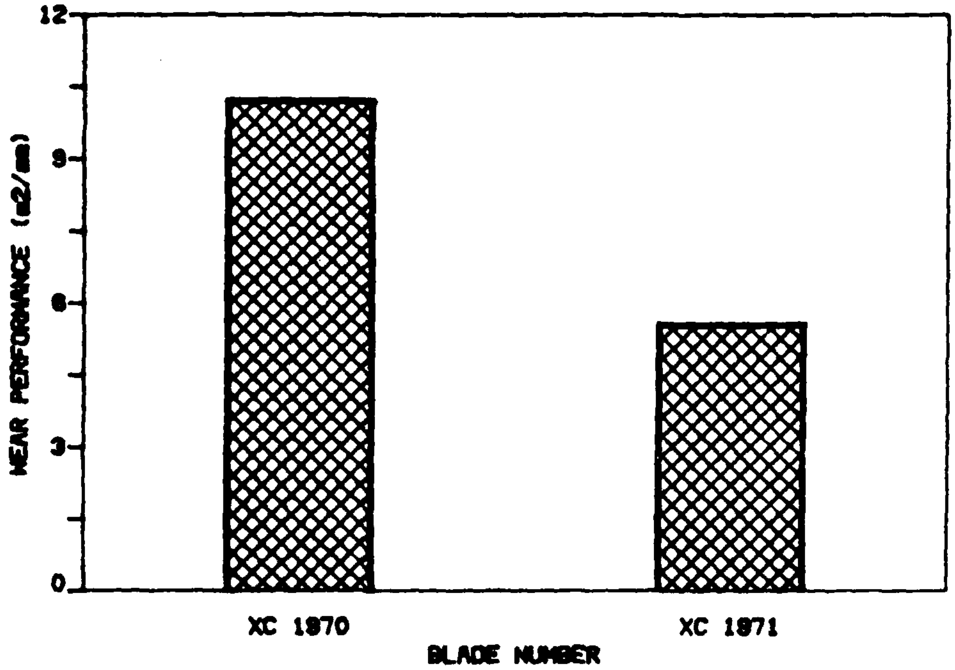


Figure D-1. Test 1 at 2903 cm^2/min.



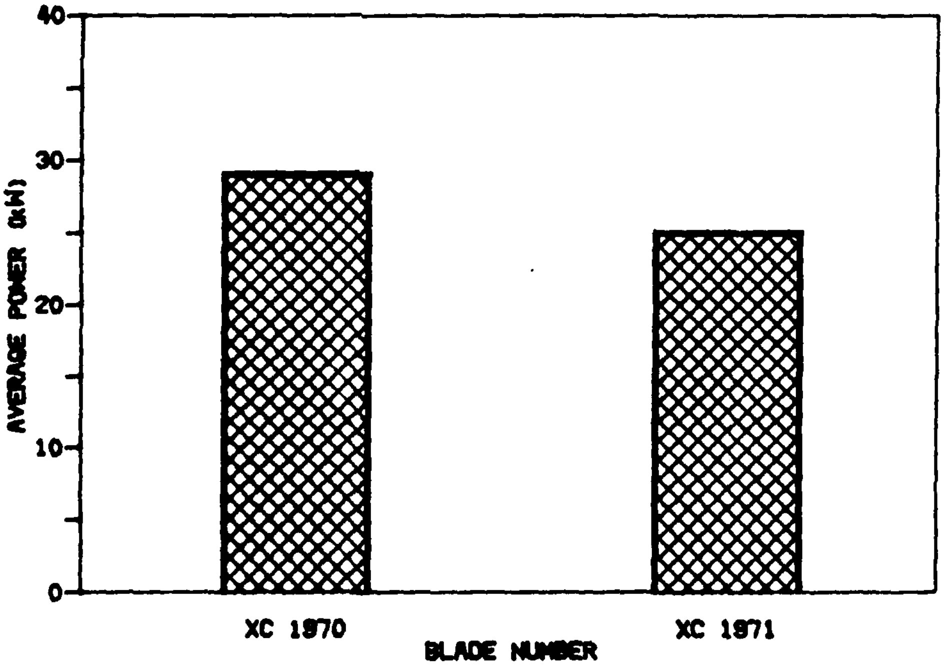


Figure D-2. Test 2 at 3771 cm^2/min

TABLE D-2. SAWING CONDITIONS USING A PATCH-WEGNER 37.3 KW ELECTRIC SAW.

PARAMETER	TEST 1	TEST 2
Downfeed	177.8 mm	177.8 mm
Traverse Rate	163.3 cm/min	212.1 cm/min
Cutting Rate	2903 cm^2/min	3771 cm^2/min
Arbor Speed	1450 RPM	1450 RPM
Blade Surface Speed	47 m/sec	47 m/sec
Coolant Flow Rate	38 liters/min	38 liters/min

TABLE D-3. BLADE PERFORMANCE DATA TEST NO. 1 AT 2903 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	#Crystals/ cm^2
XC 1970	21.7	12.4	55	13	32	Fair	29
XC 1971	18.6	7.9	45	13	42	Fair	20

*Whole Crushed Popout

TABLE D-4. DATA TEST 1.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)	Remarks
XC 1881				Core cracked during pretest
XC 1970	7.6	.615	.033	
XC 1971	7.6	.958	.071	

TABLE D-5. BLADE PERFORMANCE DATA TEST NO. 2 AT 3771 cm^2/min.

Blade Number	Average Power (kW)	Wear Perf (m^2/mm)	Crystal Condition % *W	C	P	Bondtails/ Protrusion	#Crystals/ cm^2
XC 1970	29.4	10.1	43	15	42	Fair	29
XC 1971	25.4	5.8	39	20	41	Fair	22

*Whole Crushed Popout

TABLE D-6. DATA TEST 2.

Blade Number	Amount Sawn (m^2)	Radii Wear (mm)	Thickness Wear (mm)	Remarks
XC 1970	4.4	.432	.033	Core cracked after 2nd test
XC 1971	4.3	.744	.124	Core cracked after 2nd test

Test 1 (Figure D-1, Tables D-2, D-3, and D-4) was conducted at a cutting rate of 2903 cm^2/min (31.2 ft^2/min). Blade XC 1970 required higher power and had better wear performance than Blade XC 1971. Blade XC 1970 also had a higher number of crystal sites per square centimeter on the cutting surface.

Test 2 (Figure D-2, Tables D-2, D-5, and D-6) was conducted at a cutting rate of 3771 cm^2/min (4.06 ft^2/min). Blade XC 1970 required higher power and had a better wear performance than Blade XC 1971. Blade XC 1970 also had a higher number of crystal sites per square centimeter on the cutting surface. Both Blade XC 1970 and Blade XC 1971 developed gullet cracks during test 2.

Reduction of the diamond concentration from 20 to 15 percent resulted in lower power requirement to achieve a fixed cutting rate.

APPENDIX E

USEFUL CONVERSION FACTORS

TABLE E-1. CONVERSION FACTORS.

TO OBTAIN	MULTIPLY	BY
HP	kW	1.341
in.	cm	0.3937
ft.	cm	3.281×10^{-2}
$\frac{ft^2}{min}$	$\frac{cm^2}{min}$	1.076×10^{-3}
$\frac{ft^2}{0.001"}$	$\frac{m^2}{mm}$	0.273
$\frac{in^2}{0.001"}$	$\frac{m^2}{mm}$	39.37
$\frac{gal}{min}$	$\frac{liters}{min}$	0.264

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